92-01263/

STRATEGIC STUDY OF FUTURE IRONMAKING PROCESSES

VOLUME II - PROCESS DESCRIPTIONS

Final Report
by

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Work on this project was conducted under the auspices of the Department of Energy, Mines and Resources.

DSS File Number:0095Q.23440-8-9085
DSS Contract Number:23440-8-9085/01-SQ
EMR Scientific Authority:Mr. M. C. Campbell

This work was supported jointly by:

Algoma Steel Corporation
Canada Centre for Mineral and Energy Technology (CANMET)*
Canadian Carbonization Research Association (CCRA)
Canadian Liquid Air
Canadian Steel Industry Research Association (CSIRA)
Iron Ore Company of Canada, Limited
Linde Division of Union Carbide
National Slag Company
Ontario Hydro
Stelco Inc
Union Gas Company

* funding through the Federal Panel on Energy R&D (PERD)

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A 1. COAL IRON GASIFICATION PROCESS (CIG)

Developer:

A joint Japan-Sweden feasibility study for the International Energy Agency (IEA). Japanese contractor was Japan Iron and Steel Federation. Japanese project team was drawn from Nippon Steel Corporation, Nippon Kokan KK, and Kobe Steel Ltd.

Swedish contractor was National Swedish Board for Technical Development (STU). Swedish project team was drawn from Interproject Services AB, the Royal Institute of Technology, and the Foundation for Metallurgical Research (MEFOS).

Purpose:

To decrease the energy required to produce hot metal (assumed from IEA sponsorship).

Principles:

Iron ore would be reduced either in a shaft furnace (lump ore, pellets, etc) or in a fluidized bed (fine ore) using the off-gases from the melter unit (see Figures 1 and 2). The melter unit would employ the injection of fine coal and oxygen into the molten iron bath (would need to start each heat with a liquid hot heel); it would use both top and bottom blowing.

Figure 1: CIG Process (STI, 1984)

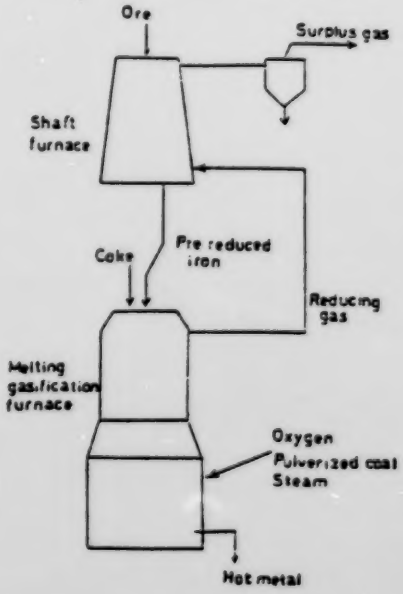
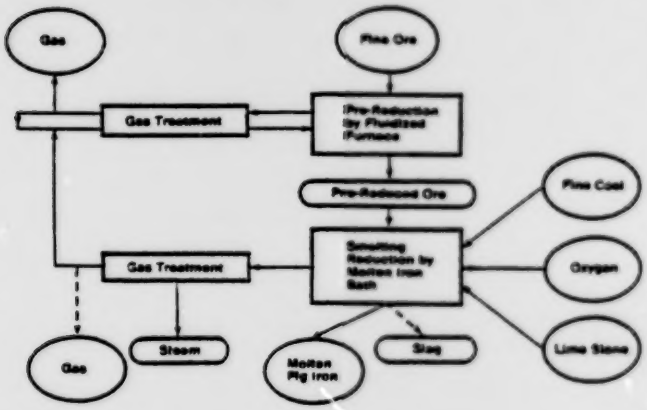


Figure 2: Flowchart of the CIG Smelting Reduction Process using a Molten Iron Bath (Smith and Corbett, 1985)



The Japanese team studied the iron and steelmaking process while the Swedish team looked at the reduction/coal gasification side.

Status:

- This study consisted of a technical and economic evaluation of a converter-type melter linked with a direct reduction unit - entirely a study on paper.
- The economic evaluation showed little, if any, advantage for this process over the blast furnace; this ironmaking process was not pursued further.
- As a result of the gasification studies, a pressurized gasification pilot plant was built at MEFOS which is financially supported by the Swedes and Nippon Steel.

Potential Contacts:

K-O Jonssen - SSAB
C-L Axelsson - Royal Institute of Technology, Sweden
K. Torssell - Royal Institute of Technology, Sweden
B. Törneman - Interproject Service AB, Bettna, Sweden
K. Sato - Nippon Steel Corporation, Japan (in the past dealing with P-CIG, Mefos)

References:

- D. Kaneko and E. Kurihara, "Economic Prospects for Smelting-Reduction Processes", 1984, Steel Times International (STI), June, pp 33 to 38.
- "CIG Process", 1984, Steel Times International, June, pp 41 to 43.
- R. B. Smith and M. J. Corbett, "Coal-Based Ironmaking - A Study", 1985, ECSC-Sponsored Research Project Agreement No. EC1-1274-B7240-84UK, BSC Ref: FR 158-3/852, September.
- C-L Axelsson et al, "The CIG Process for Smelting Reduction and Coal Gasification", 1986, Process Technology Conference Proceedings, Fifth International Iron and Steel Conference, AIME/ISS, Washington, DC, April 6 to 9, pp 1041 to 1048.
- C-L Axelsson et al, "The P-CIG Process for Generation of a Pure Pressurized Reduction Gas", 1988, Proceedings, 7th Process Technology Conference, AIME/ISS, Toronto, Canada, April 17 to 20, pp 241 to 250.

A 2. CBF PROCESS (Converted Blast Furnace Process)

Developer:

British Steel Corporation (BSC)
The Hoogovens Group of the Netherlands
- first separately, then jointly

Purpose:

- To produce liquid iron with coal instead of coke as the energy raw material.
- To make as much use of existing blast furnace equipment as possible.
- To arrive at a process for ironmaking which can be fitted into existing integrated steel plants.
- To make a product which is fit for producing low cost steel.

Principles:

The process developed consists of three main elements (Figure 3).

1. A counter-current direct reduction shaft in which a burden of pellets, sinter or lump ore is partially reduced at 800° to 900°C with reducing gas issuing from an iron bath coal gasifier.

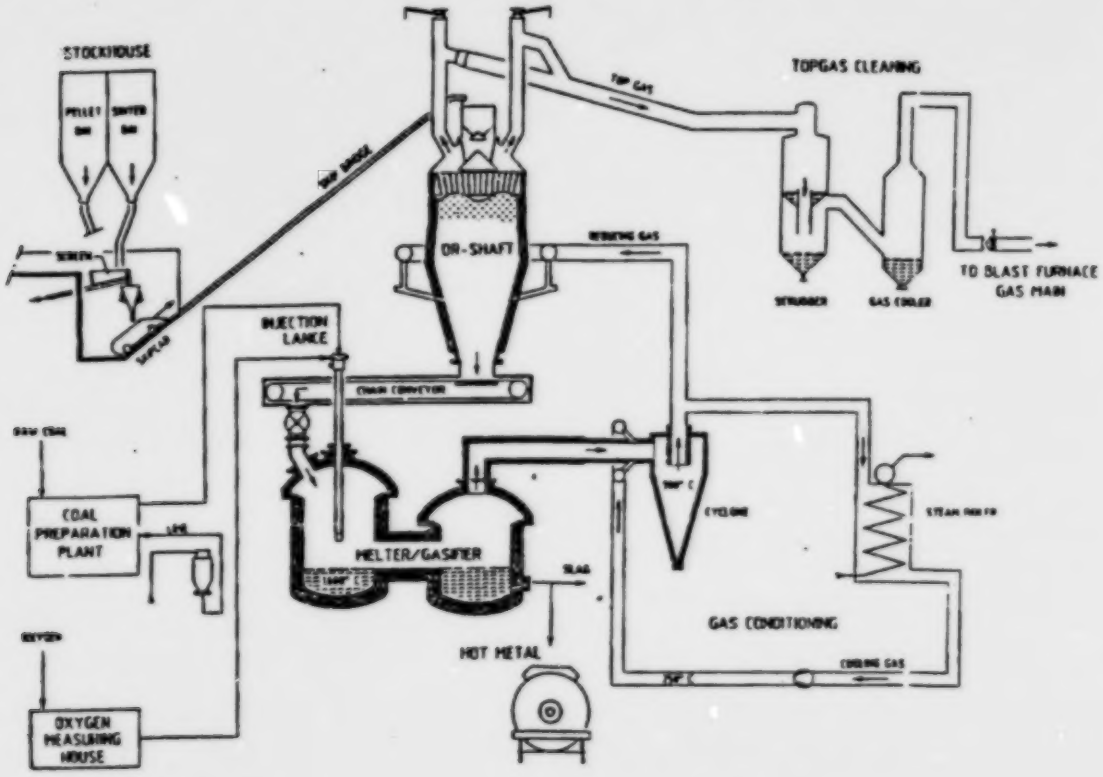
2. An iron bath coal gasifier equipped with a vertical lance for top injection of coal and oxygen. This element comprises the first chamber of a unique two-chamber gasifier/melter.

3. Gas conditioning, in which the melter off-gas is cleaned and cooled to reduction temperature before entering the reduction shaft.

Status:

- Extensive physical and mathematical modeling, pilot plant melter studies and many engineering and costing considerations have been completed.
- A process engineering flow sheet has been quantified to serve as the basis for the installation engineering for the rebuilding of the 1000 tonnes/day blast furnace no. 3 of Hoogovens, Ijmuiden, to a 1000 tonnes/day CBF.
- As of Nov/Dec 1988, the decision to rebuild Hoogovens BF3 into a 1000 tonnes/day CBF demonstration unit was still open (cost £45 million); BSC and Hoogovens were negotiating with further potential partners to proceed.
- CBF process is on hold (November 1989) essentially for the duration of the high coal injection tests on BSC's Cleveland Works blast furnace (end of 1991). The concept is being changed and engineering for the new process is expected to be completed by the end of 1991. Process development is expected to take until the mid 1990s. The revised process is being called the CCF process, but our contact would not say what these initials stand for.

Figure 3: Converted Blast Furnace Flow Sheet (van Langen and Smith, 1988)



Potential Contacts:

Dr. J. M. Van Langen - Hoogovens, Ijmuiden
Dr. R. B. Smith - BSC, Teesside Laboratories
Mr. M. J. Corbett - BSC, Teesside Laboratories

References:

- J. M. van Langen and R. B. Smith, "The Converted Blast Furnace", 1988, Journées Sidérurgiques ATS, Paris, November 30 to December 1.
- "News from Industry", 1989, Ironmaking and Steelmaking, Vol 16, No. 3, pp 148 to 149.
- "Converted Furnace Makes Steel Cheaper, Without Coke", American Metal Market, March 17, 1989.
- "Future Steelmaking", 1988, Report of AISI Task Force on Direct Steelmaking, March.
- "CBF Process", Technical Update, BSC, Issue No. 1, Summer 1989, p 18.
- J. M. van Langen and R. B. Smith, "Nouveau Procédé d'élaboration de la Fonte au Haut Fourneau", 1989, La Revue de Métallurgie - CIT, October, pp 759 to 764. In French, English abstract - "The Converted Blast Furnace Process".
- J. M. van Langen and R. B. Smith, "Converted Blast Furnace Reduces Ironmaking Costs", 1989, Steel Times International, July, Vol 13, No. 3, p 15.

A 2(a). CBF PROCESS FORERUNNER (BSC Continuous Melter/DR Process)

Developer:

British Steel Corporation

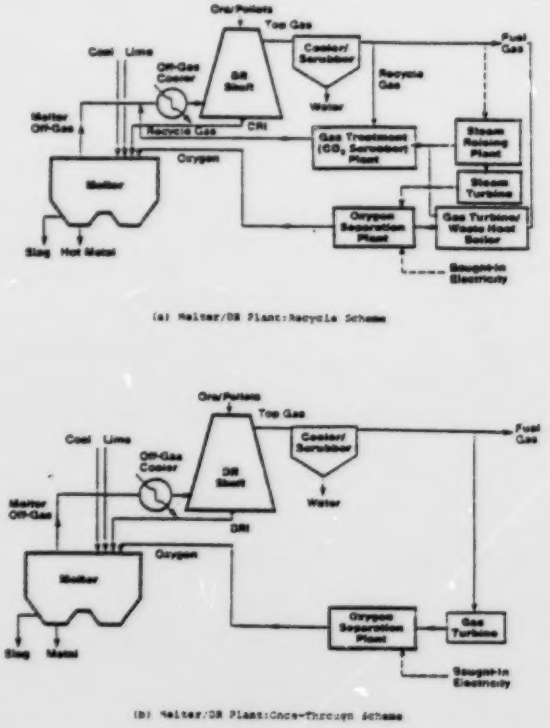
Purpose:

This process evolved from developments aimed at increasing the scrap consumption in the BOF process by coal and oxygen additions and from studies of coal-based direct reduction for application on the BSC Midrex plants at Hunterston.

Principles:

The melting unit is conceived as a twin-chambered fixed unit (Figure 4) with one chamber acting as the melting vessel into which coal, oxygen and DRI are fed, and the other chamber, into which the metal and slag flow, acting as a settling vessel for separating slag and hot metal. Coal and oxygen would be introduced by a top lance, while bottom stirring would ensure good mixing.

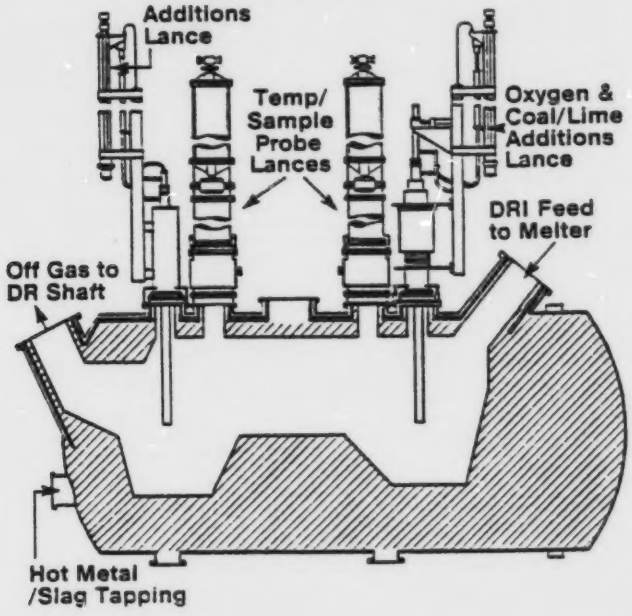
Figure 4: BSC Continuous Melter/DR Process (Smith and Corbett, 1985)



The unit would be a fully sealed, pressurized system (operating pressure up to 5 bar).

The direct reduction unit would be counter-current shaft-type. DRI would be transferred hot from the reduction shaft to the melter vessel (Figure 5).

Figure 5: Schematic of BSC Melter Unit (Smith and Corbett, 1985)


Additions Lance
Temp/ Sample Probe Lances
Oxygen & Coal/Lime Additions Lance
DRI Feed to Melter
Off Gas to DR Shaft
Hot Metal /Slag Tapping

Status: (1985)

- Extensive trials completed in a 3-tonne pilot oxygen converter at BSC Teesside Laboratories.
- Feasibility of controlled melting with carbon and temperature control fully demonstrated.
- A purpose-built melter unit being installed which will permit fully continuous operation (planned to be commissioned in 1985).
- A detailed engineering design feasibility study for an integrated melting and reduction plant has been undertaken.
- Plans for immediate future were to concentrate on the continuous melter pilot plant studies.

References:

- R. B. Smith and M. J. Corbett, "Coal-Based Ironmaking - A Study", 1985, ECSC-Sponsored Research Project, Agreement No. EC1-1274-B7240-84UK, BSC Ref: FR 158-3/852, September.
- A. L. Robson et al, "Pilot Plant Study of Smelting Reduction of Iron Ore with Coal and Oxygen", 1987, Proceedings Pyrometallurgy 87, Institute of Mining and Metallurgy, London, UK, September 21 to 23, pp 879 to 905.
- J. M. van Langen and R. B. Smith, "The CBF Process for Coal-Based Ironmaking", 1989, Stahl und Eisen, Vol 109, No. 19, pp 71 to 74 (in German), p 148 (English Abstract).
- D. Naden, "Fluid Bed Ore Reduction Technology for Direct Smelting Processes", 1987, Proceedings Ironmaking Conference. AIME/ISS, Pittsburgh, PA, April, Vol 46, pp 409 to 419.

A 2(b). CBF PROCESS FORERUNNER (The Hoogovens Process)

Developers:

Hoogovens Group, The Netherlands

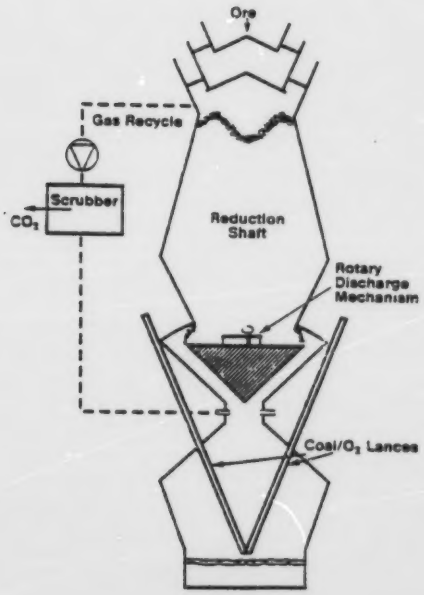
Purpose:

The melting process has evolved from developments aimed at increasing the scrap consumption in the BOF by coal and oxygen additions. The aim of the Hoogovens program is to develop a process which can be applied when their No. 6 Blast Furnace (11 m hearth) becomes due for rebuilding in five to ten years' time.

Principles:

The concept of the Hoogovens process is shown in Figure 6. Its key feature is that it could be implemented by modifying an existing blast furnace.

Figure 6: Melter Unit (Smith and Corbett, 1985)



In the melter, oxygen and coal are injected by separate lances. The aim was to control in-vessel combustion and bath stirring by adjustment of lance height and direction of delivery. The off-gases are cooled to direct reduction temperature by injection of scrubbed recycled top gas. Reduction is performed in a blast furnace type stack and the reduced iron ore is fed hot into the melter.

Status:

- Development of the process has been mainly by studies of coal-fired melting in the BOF.
- Hoogovens and BSC have collaborated on the development of bath agitation, in-vessel combustion, and coal additions. Work at Hoogovens has been on their 100-tonne converters in their No. 1 Steel Plant.
- Supplementary thermodynamic calculations have been completed.
- Next step is conversion of a small blast furnace to demonstrate the process and complete its development.
- Proposal to the European Coal and Steel Community (ECSC) for demonstration project in collaboration with BSC and Korf Engineering in 1984 did not receive support.
- 1985 - proposal to modify Hoogovens BF3 to a pilot demonstration plant, capacity of 500 to 1000 tonnes/day is under consideration by the Hoogovens Board. Proposal was turned down.

References:

- R. B. Smith and M. J. Corbett, "Coal-Based Ironmaking - A Study", 1985, ECSC-Sponsored Research Project, Agreement No. EC1-1274-B7240-84UK, BSC Ref: FR158-3/852, September.

A 3. COIN PROCESS (Coal Oxygen Injection Process)

Developer:

Fried Krupp Research Institute, Essen

Purpose:

The COIN process was originally conceived as a process for melting scrap or other metallic feedstocks using coal and oxygen injected into a BOF-type converter vessel. The concept was subsequently extended to a combined reduction/melting configuration in which the cooled (to reduction temperature) off-gases are used directly in the reduction unit.

Principles:

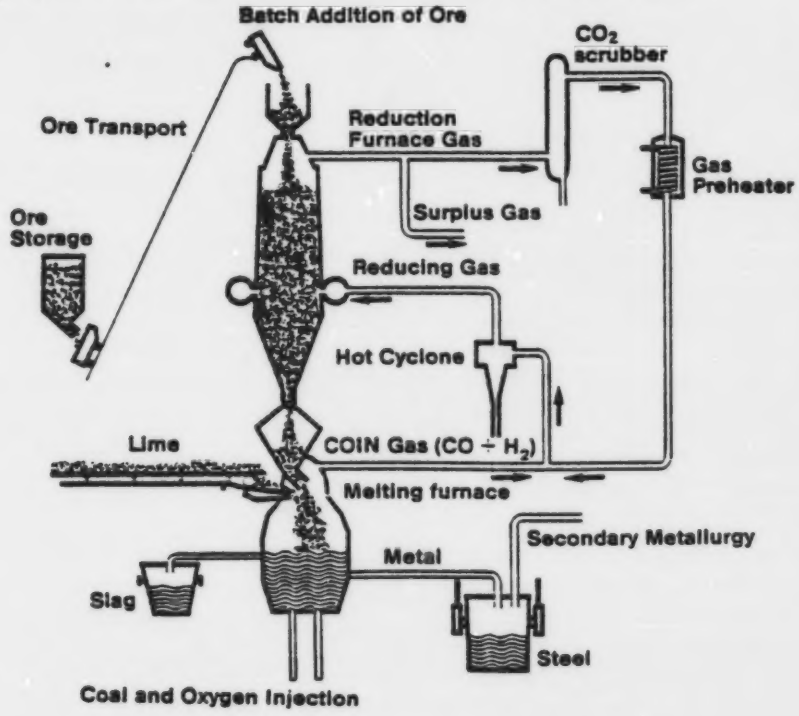
The process is a combined direct reduction/melting process in which the cleaned hot gases from the melting furnace reduce the ore; the degree of reduction is ≥90 percent. The concept is to hot charge the DRI into the melter.

Krupp envisage reduction being performed in a fluidized bed for the fully developed process (fine ores). However, their concept for a first generation plant incorporates the proven shaft furnace (lump ore or pellets) for reduction (Figure 7). In addition, the DRI from the first generation plant would be cooled before being charged to the melter.

Status:

- The melting step has been researched extensively on a 3-tonne converter (experimental converter) in which fine coal and oxygen were injected into the base of the vessel through annular tuyeres.
- An outline design for a plant to produce 900 000 tonnes/yr hot metal has been made; projected capital cost (1983) DM530 million to DM625 million (US $294 to $347 million at 1.8 DM/US$).
- Through 1986/87 developers planned continued experimentation on the pilot plant with particular emphasis on fluidized bed reduction. In addition, the COIN tuyere and coal injection were to be tested in a Krupp steelworks.
- As of 1985, there were no plans to build a demonstration plant.
- No further work on this process is anticipated.

Figure 7: Coal and Oxygen Injection (Smith and Corbett, 1985)



Potential Contacts:

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J. Hartwig - Krupp Forschungsinstitut, Essen
D. Radke - Krupp Forschungsinstitut, Essen
W-D Röpke - Krupp Industrie und Stahlbau, Duisburg

References:

- R. B. Smith and M. J. Corbett, "Coal-Based Ironmaking - A Study", 1985, ECSC-Sponsored Research Project, Agreement No. EC1-1274-B7240-84UK, BSC Ref: FR 158-3/852, September.
- E. Aukrust et al, "Steelmaking Technology for the 21st Century. State-of-the-Art", 1984, AISI Task Force Report, August.
- K. H. Ulrich and D. Neuschütz, "Latest Developments at Krupp in the use of Coal for Direct Reduction", 1983, Steel Times, July, pp 366 to 368.
- J. Hartwig et al, "Krupp Concept of a Combined Direct Reduction - Melting Process", 1983, Ironmaking and Steelmaking, Vol 10, No. 3, pp 124 to 129.
- D. Neuschütz and T. Hoster, "Concept and Present State of a Coal-Based Smelting Reduction Process for Iron Ore Fines", 1989, Steel Research 60, Verlag Stahleisen mbH, No. 3 + 4, pp 113 to 119.

A 4. COMBISMELT PROCESS

Developer:

Lurgi
Mannesmann-Demag Huttentechnik

Purpose:

To produce liquid iron intermediate in carbon level between hot metal and steel.

Principles:

Combismelt flowsheets are shown in Figures 8 and 9.

Figure 8: Flow Sheet for Alternatives of Reduction Process and Steelmaking (Lehmkuhler et al, 1986)

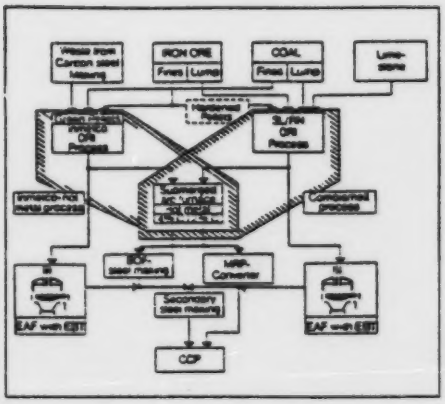
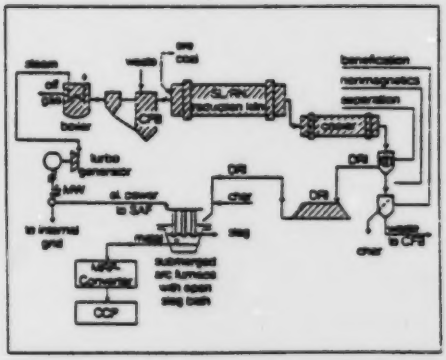


Figure 9: Combismelt-Process in Front of the MRP-Converter and Continuous Casting (Lehmkuhler et al, 1986)



The raw materials - iron ore, coal, and limestone or dolomite - are charged in the required ratios to the rotary kiln. The process works with lump ore or hardened pellets and can accommodate rather high levels of ash in the coal. The dolomite or limestone binds the sulfur so as to avoid a pickup of sulfur in the DRI.

In the preheating zone, the iron ore and coal are dried and heated to reduction temperatures; the volatile matter of the coal is released.

In the reduction zone, the iron ore is reduced to 92 percent metallization. The temperatures required by the process are provided and controlled by rates of combustion air injected through shell blowers arranged along the kiln length.

Upon being discharged from the rotary kiln, the DRI is cooled indirectly to ambient temperature together with the nonmagnetics in the discharge (mixture of char and dolomite) in a rotary cooler.

Separation of the DRI from the nonmagnetics is effected by screening and magnetic separation.

The hot off-gases from the rotary kiln flow counter-current to the material flow, exiting the kiln at the feed end for further use in an energy reclaiming system.

The SL/RN process is capable of accepting:

- raw materials like low grade iron ore or noncoking coal,
- coal as the sole energy source for producing DRI.

The capacity of a rotary kiln ranges from about 30 000 t/yr to 250 000 t/yr of DRI.

It is part of Combismelt Technology to use the total surplus of energy for running a co-generation power plant which subsequently covers the electricity demand for the submerged arc furnace (SAF).

In the SAF, the low carbon DRI (maximum 0.2 percent C) will be melted. The nonmetallic components form the slag, together with lime and other fluidizers. By the addition of carbon, which may come from the kiln discharge, the carbon content of the liquid metal can be raised to approximately 2.0 percent, depending on the FeO content in the slag.

This liquid metal is then converted to liquid steel ready for casting in a metal refining process (MRP) or BOF.

Status:

Essentially no new technology is involved. Combismelt has potential for commercialization under the right economic conditions, but commercialization is not being actively pursued (1989).

Potential Contacts:

Demag Steel Plant Technology GmbH, D-4100 Duisburg

H. J. Lehmkuhler, Chief Engineer, Processing
F. P. Pleschiutschnigg, Chief Engineer, Processing
H. Vorwerk, Managing Director

Lurgi Chemie

W. Janke, Vice President

References:

- H. J. Lehmkuhler et al, "Advanced Steelmaking for Minimills from Low Grade Materials to High Grade Flat and Long Products", 1986, SEAISI Quarterly, October, pp 29 to 38.
- R. B. Smith and M. J. Corbett, "Coal-Based Ironmaking - A Study", 1985, ECSC-Sponsored Research Project, Agreement No. EC1-1274-B7240-84UK, BSC Ref: FR 158-3/852, September.

A 5. COREX PROCESS
(Originally KR Process - Kohle Reduction Process)

Developer:

A joint development between Korf Engineering, FRG, and Voest-Alpine, Austria, with financial support from the Austrian Research Promotion Foundation and the Ministry for Research and Technology, FRG.

The technology is now owned/marketed by Deutsche Voest-Alpine Industrieanlagenbau (DVAI), the successor to Korf Engineering, and Voest-Alpine Industrieanlagenbau (VAI).

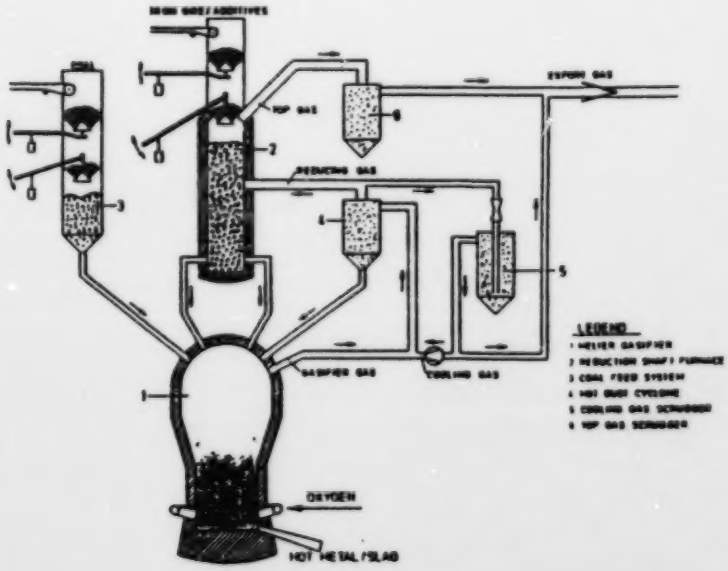
Purpose:

To develop a process for the production of hot metal that would by-pass the coking step and be able to use a wide range of coals.

Principles:

The two main process units are a fluidized bed melter-gasifier and a counter-current reduction shaft (Figure 10).

Figure 10: The COREX Process Basic Flow Sheet with Export Gas (Feichtner, 1989)



The melter-gasifier is a refractory-lined vessel designed to operate at pressures up to 5 bar. It has a hemispherical top and decreasing cross section to a parallel-sided melting zone and hearth. In operation, a bed of coal char is maintained in the gasifier by addition of raw coal which is dried and devolatilized in the bed. Oxygen is injected through radially disposed sidewall tuyeres and DRI from the reduction unit is fed into the melter-gasifier where the heat from the combustion of char with oxygen melts it, the molten metal collecting in the hearth at the bottom of the reactor. The metal and slag are tapped periodically using blast furnace technology. The gases evolved from combustion of the coal char and devolatilization of the coal are strongly reducing and are taken off to form the gas feed to the reduction unit.

The reduction shaft is a Midrex type; feed is lump ore or agglomerated concentrates. Discharge material is fed hot to the melter-gasifier.

Spent top gas is cleaned and cooled and is then available as an export fuel gas.

Status:

- Development started in the late 1970s when natural gas prices increased dramatically.
- 1979/1980: conceptual and pilot plant construction phase.
- Pilot plant studies at Kehl-am-Rhine, FRG, started in 1981. Capacity 60 000 tonnes/yr. Process development to 1983.
- Pilot plant operated in various campaigns totaling 8000 hours - testing great variety of lump ores, sinters, and pellets, as well as various coal grades from high volatile, high ash coals to anthracite.
- 1985 ISCOR ordered 300 000 tonnes/yr plant, i.e. first commercial plant.
- August 1988, ISCOR plant successfully started up.
- Subsequently plant was down for several months for repairs and modifications.
- October 1989, plant started up again successfully and "COREX so far is the only industrially proven smelting reduction process that is commercially available in the world".
- June 22, 1990, official commissioning of COREX plant at ISCOR's Pretoria Works.

Potential Contacts:

Dipl-Ing Hanns Feichtner, Chairman and President - DVAI, FRG
W. Jarvers - DVAI
Dr.-Ing W. Maschlanka, Director Process Development
R. Hauk
B. Vuletic
W. Kepplinger - Voest Alpine AG, Austria
H. van der Merwe - ISCOR Pretoria Works, RSA
Dipl-Ing Franz Helten - DVAI Technical Sales
J. Flickenschild

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A 6. DAVY-McKEE PROCESS

Developer:

Davy McKee Research and Development, UK

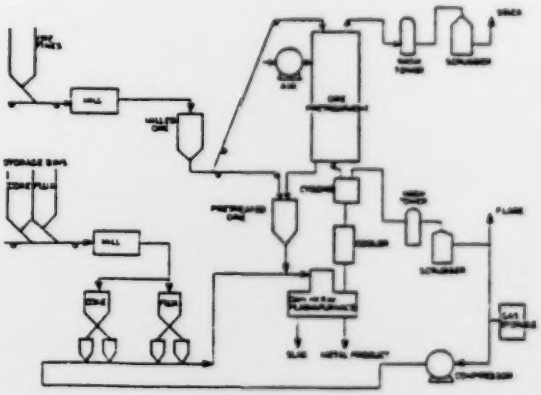
Purpose:

Davy McKee have developed unique plasma technology, based on the Plasmacan furnace design, for treating ore and metal fines. The plasma furnace technology in combination with fluid-bed ore reduction offers a direct, compact and economic process route from ore fines to hot metal product. The same plasma furnace technology can also be applied to metal recovery from metal fines and EAF dust processing.

Principles:

Figure 11 is a diagrammatic representation of the Davy-McKee process.

Figure 11: Davy McKee Integrated Ore Reduction and Plasma Smelting Process Flowsheet (Naden and Kershaw, 1986)



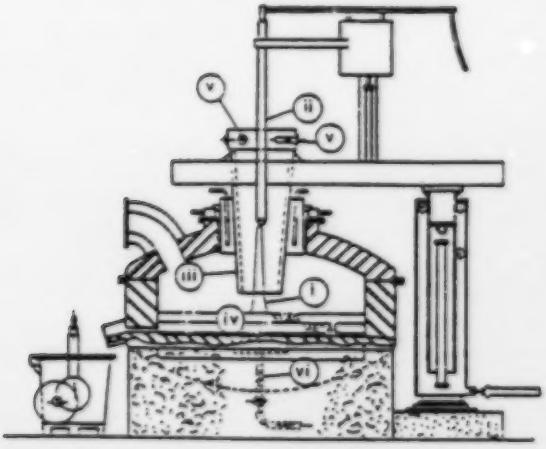
- Ore fines are segregated and the oversized fines are milled (where appropriate) to give an ore feed suitable for treatment in both the fluid bed pretreatment plant and the plasma furnace. Typical size range is - 4 mm plus 0.1 mm.
- Ore within the size specification is fed to the milled ore storage bin, then conveyed to the first stage of the ore pretreatment section. The unpretreated ore may, if required, be conveyed directly to the ore feed hopper in preparation for feeding directly to the plasma furnace, e.g. for start-up.

- The ore is pretreated in a multistage fluid bed ore pretreatment using the plasma furnace product gas. Ore pretreatment consists of:

  - ore preheating, using the residual calorific value of the gas from the subsequent ore pretreatment stages,
  - ore calcination to remove dissociation products (if appropriate),
  - ore prereduction by plasma furnace gas, leaving sufficient oxygen in the ore to generate the quantity of gas in the plasma smelting furnace required for the effective operation of the pretreatment section.

- Pretreated ore is conveyed to the pretreated ore storage hopper in preparation for feeding to the plasma furnace.
- Coal and flux are prepared to a size specification (usually - 4 mm) and stored in feed storage hoppers. If appropriate, flux may also be pretreated in the fluid bed plant.
- Ore, coal and flux are transported separately from the sealed feed hoppers to the Davy McKee plasma furnace sleeve reactor using gas recycled from the plasma furnace exit. Solids are transferred from the hoppers to the gas stream by conventional equipment.
- The design of the dc transferred arc Plasmacan furnace is similar to that shown in Figure 12. The plasma furnace gas temperature will be similar to the smelting temperature, i.e. approximately 1400°C to 1600°C, and cooling to less than 800°C will be necessary before the gas can be used in the ore prereduction step.

Figure 12: Davy-McKee Plasma Furnace Design (Naden and Kershaw, 1986)



- A portion of the plasma furnace gas stream is diverted to be recycled as feed injection gas. The gas is washed, scrubbed, and compressed for this purpose. A gas storage facility is included in this line for start-up purposes.
- Effluent gas from the ore pretreatment section is washed then flared.
- Molten products are tapped periodically from the furnace.

Status:

- The operation of the Davy-McKee fluidized bed ore reduction technology is commercially proven. A continuing program of development has provided extensive data on the reduction of iron and manganese ores. A predictive design technique is available using data from bench-scale tests for a wide range of gas mixtures derived from coal and coke.
- The design principles of the Davy-McKee plasma furnace have been proven in a pilot plant program operated at a scale of 0.35 MW. The extensive program has resulted in sufficient data being accumulated to design smelting furnaces made up of multiples of the sleeve reactor concept, each with a capacity up to 10 MW. A 5 MW furnace was slated to be operating in 1986 producing a range of hot metal products.
- Pilot plant and bench-scale studies, together with engineering design studies, have established the feasibility of combining fluidized bed ore prereduction and plasma smelting in processes to produce iron and ferro alloys.
- The application of the Davy-McKee plasma furnace to the treatment of metal fines has been confirmed in tests in the plasma furnace pilot plant. Good mass accountability and high efficiency of electrical energy utilization was achieved. Experience obtained on both ores and metal fines indicates that the technology will also be applicable to the treatment of a wide range of steel plant dust arisings.

Potential Contacts:

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Mr. Paul Kershaw

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Bowesfield Lane
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Cleveland, TS18 3HA
UK

References:

- D. Naden and P. Kershaw, "Fluid-Bed Ore Reduction and Plasma Smelting Technology for Metal Production from Ore and Metal Fines and EAF Dusts", 1986, Steelmaking Proceedings, 5th International Iron and Steel Congress, Washington, DC, Vol 69, pp 51 to 58.
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A 7. DIRECT IRON ORE SMELTING PROCESS (DIOS)

Developer:

Nippon Kokan KK (basic process)
The Japan Iron and Steel Federation (joint development to a proven process)

Purpose:

To develop a new ironmaking process which will overcome the shortcomings of the blast furnace process, with due regard to the restrictions of Japanese integrated steel works. Thus, it should have the following characteristics:

- low capital cost,
- high flexibility,
- ability to use, directly, coarse and fine ore (like sinter feed),
- ability to use, directly, noncoking coal, and
- supply the optimum quantity of surplus energy (1 to 2 Gcal/thm) with low coal consumption.

Principles:

Figure 13 is a schematic diagram of the DIOS process being developed by the JISF.

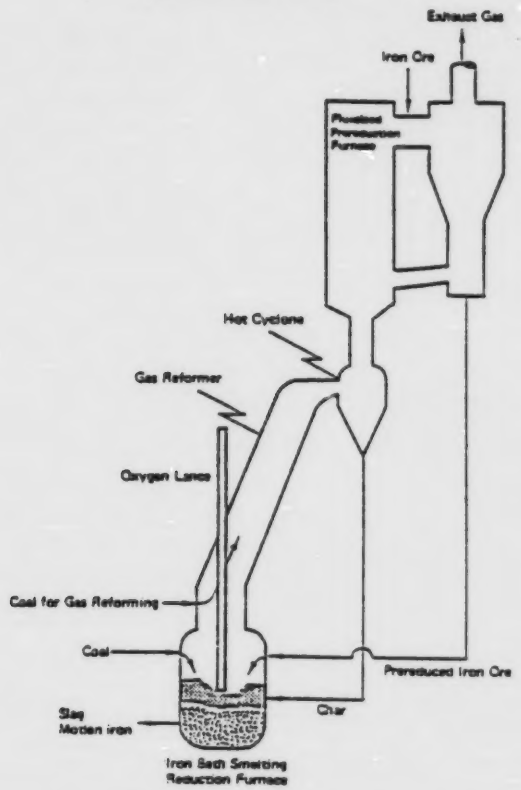
The DIOS process has three possible configurations:

- the smelting-reduction furnace only,
- the smelting-reduction furnace coupled to a prereduction furnace, and
- the coupled smelting-reduction furnace and prereduction furnace in combination with a coal gas reformer and/or a CO_2 removal system.

When the smelting-reduction furnace and the prereduction furnace are connected, the connecting pipework is used as a coal-based gas-reforming furnace; details of its design and functional capabilities were not provided by the JISF. The pilot plant will be designed for in-bath smelting, the technology that NKK had been working to develop. The furnace for prereduction had not been designed at the time of our visit, but it, too, will be built at the pilot plant at Keihin Works. In-bath smelting was selected for:

- high productivity,
- flexibility (wide range) in coal selection,
- high post-combustion, and
- the direct use of lump or coarse coal and ore. (For kinetic reasons, the maximum size of the ore is limited to about 8.0 mm.)

Figure 13: Conceptual Drawing of DIOS-Process (JISF) (Fukushima 1990)



A fluidized bed reactor was selected for the prereduction step so as to avoid the necessity of agglomerating the ore. A low degree of reduction is easier to obtain in a fluidized bed reactor than a high degree of reduction, which fits the strategy of keeping the degree of prereduction low, about 20 percent, so as to not jeopardize the in-plant energy export. The consequence of this approach, of course, is lower efficiency of the smelting-reduction furnace.

The connecting of the prereduction and smelting-reduction furnaces is still a major problem to be overcome. The JISF plan to maximize the use of gravity for materials handling. Consequently, the prereduction furnace must be situated above the smelting-reduction furnace, making the structure very high.

The details of the cyclone shown in Figure 13 are complex and represent one of the key technologies in materials handling in this process.

Inert gas is used to weakly stir the iron melt while a top-blown oxygen jet stirs the slag layer. Aggressive stirring by the oxygen jet quickly increases coal usage. They are investigating the best arrangement for good stirring with low energy utilization.

The hot metal is saturated with carbon and contains less silicon than blast furnace hot metal; the sulfur content is a function of the fuel rate and its sulfur content, and the slag chemistry. The slag composition is similar to that of blast furnace slag, but is higher in FeO and MgO. The slag is suitable for cement applications.

Refractories are a big technical issue. Linings of Cr_2O_3/MgO have improved performance of the smelting-reduction furnace, but at a high cost. A water-cooled lining is being considered to reduce refractory costs.

Most in-bath tests have used interrupted tapping similar to the tapping of a BOF. At their Fukuyama Works, NKK recently tested a single taphole (located at the slag/metal interface); a two-taphole approach is being considered. The determination of the best method to remove the molten products from the smelting-reduction furnace is viewed as a major unknown to be resolved prior to the commercialization of the DIOS process.

Status:

- April 1984: DIOS project was initiated by JISF. Consortium includes:
  - Nippon Steel Corporation
  - Nippon Kokan KK
  - Kawasaki Steel Corporation
  - Sumitomo Metal Industries, Limited
  - Kobe Steel, Limited
  - Nisshin Steel Company, Limited
  - Nakayama Steel Works, Limited, and
  - Godo Steel, Limited.

- 1988-1990: study of components for DIOS process by the various members of the consortium at their respective plants.
- mid 1990: begin construction of 500 t/d pilot plant at NKK's Keihin Works.
- end 1994 (plan): complete pilot plant study and complete total system study and feasibility study of DIOS process.

Contacts:

Mr. T. Fukushima - Senior Manager (Planning), R&D Task Force,
Committee for R&D on the New Iron Ore
Smelting-Reduction Process, JISF

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- T. Fukushima, "Smelting Reduction in Japan", 1990, International Symposium/Workshop on Future Ironmaking Processes, Steltech, Hamilton, Canada, June 14 and 15, pp 6-1 to 6-14.
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A 7(a). DIOS FORERUNNER (NKK PROCESS)

Developer:

Nippon Kokan KK

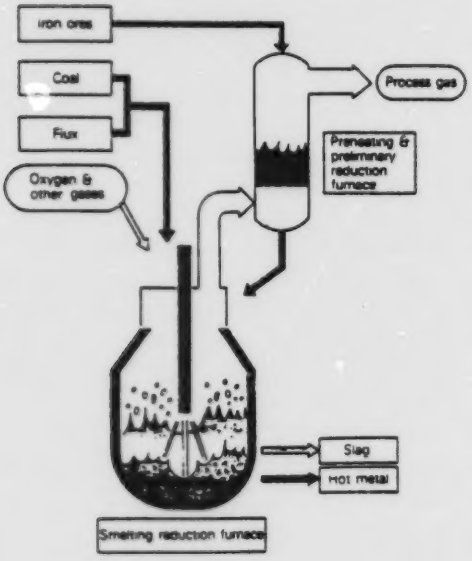
Purpose:

Replacement for blast furnace ironmaking (part of Japanese Industry initiative).

Principles:

The plant employs a fluidized bed iron ore preheating/preliminary reduction furnace linked directly to a converter (Figure 14).

Figure 14: NKK's Reduction Ironmaking Process (NKK News, 1988)



Status:

- A 5-tonnes/charge unit operated at Fukuyama Works from September 1986 to 1988.
- A 100-tonnes/day integrated smelting reduction test plant for ironmaking was completed in April 1988.

Further objectives include technological and equipment improvement and the establishment of various control technologies to realize stable operations. NKK plans to realize these objectives by 1990. DIOS, the smelting reduction project being run by the Japan Iron and Steel Federation and member companies, announced plans (mid 1989) to begin the construction of a 500 tonnes a day pilot plant this year (1990). The plant is to be installed in a steelmaking shop of NKK Corporation's Keihin Works. The construction is scheduled to be completed by 1993. The plant will then operate for a one to two year period to finalize the design of the DIOS process.

Potential Contacts:

Mr. H. Uchibori
Dr. Y. Yamaoka
Mr. H. Yanaka
Dr. K. Yamada
Mr. H. Mitsufugi

References:

- "Integrated Smelting Reduction Test Plant Operations Begin at Fukuyama Works", 1988, NKK News, June, Vol 28, No. 4, p 5.
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A 8. ELKEM POLAR PROCESS

Developer:

Elkem Technology, Norway

Purpose:

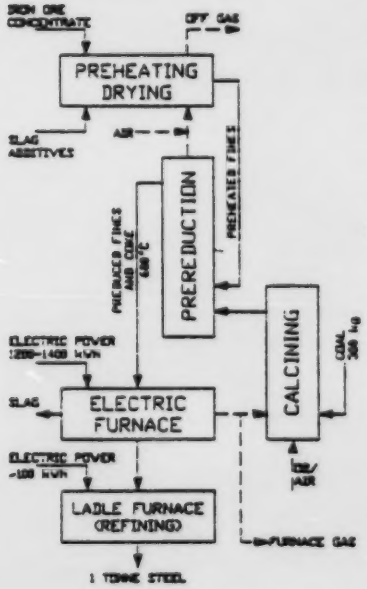
To reduce iron, manganese, chromium, and titanium ore fines to pig iron, steel, FeNi, FeMn, FeCr or titanium slags.

Principles:

The ore concentrate, along with slag additives, is dried and preheated by the burned off-gases from the prereduction unit.

Coal is calcined in the calcining unit to produce the hot reducing gas for prereduction. The "coke" and soot from the calciner can either be separated from the reducing gas or, more likely, with iron ore, be introduced into the prereduction unit with the preheated ore fines (Figure 15).

Figure 15: Principles of the Elkem Polar Process (Båsen and Ephithite, 1988)



The prereduced (to wustite) ore fines and "coke" are fed continuously into an Elkem (Soderberg electrodes) electric furnace. Melting and reduction of the ore fines in this electric furnace can be accomplished by means of an "open bath" slag process.

The semi-steel produced in the electric furnace is refined in the ladle to the desired composition and temperature.

Status:

- Completed a rigorous laboratory research program at the Norwegian Institute of Technology/SINTEF.
- In 1987 a pilot plant was completed with a nominal capacity of about two tonnes/hr at a cost of about US $6 million. It was built in conjunction with Norsk Jernverk at their facilities at Mo i Rana, in northern Norway. The pilot plant is organized as a joint venture company called Polarstål, with a 50:50 ownership by Elkem and Norsk Jernverk.
- Research program was scheduled to continue through 1988.
- Plant at Mo i Rana was scheduled to shut down at the end of 1989, which probably indicates cessation of work on the Elkem Polar Process.

Potential Contacts:

Mr. T. Båsen
Mr. R. J. Ephithite

References:

- T. Båsen and R. J. Ephithite, "The Elkem Polar Process for Reduction of Ore Fines", 1988, Proceedings, Process Technology Conference, AIME/ISS, pp 261 to 269.

A 9. ELRED PROCESS

Developer:

Stora Kopparberg Bergslag AB was the originator. In the early 1970s, Stora entered into a joint development program with ASEA and in 1975 with Lurgi.

Purpose:

To develop a new ironmaking process that would reduce costs (independence from blast furnace).

Principles:

The plant layout for a 400 000 tonnes a year Elred process plant is shown in Figure 16.

Figure 16: Plant Layout for a 400 ktpa Elred Process Plant (Smith and Corbett, 1985)

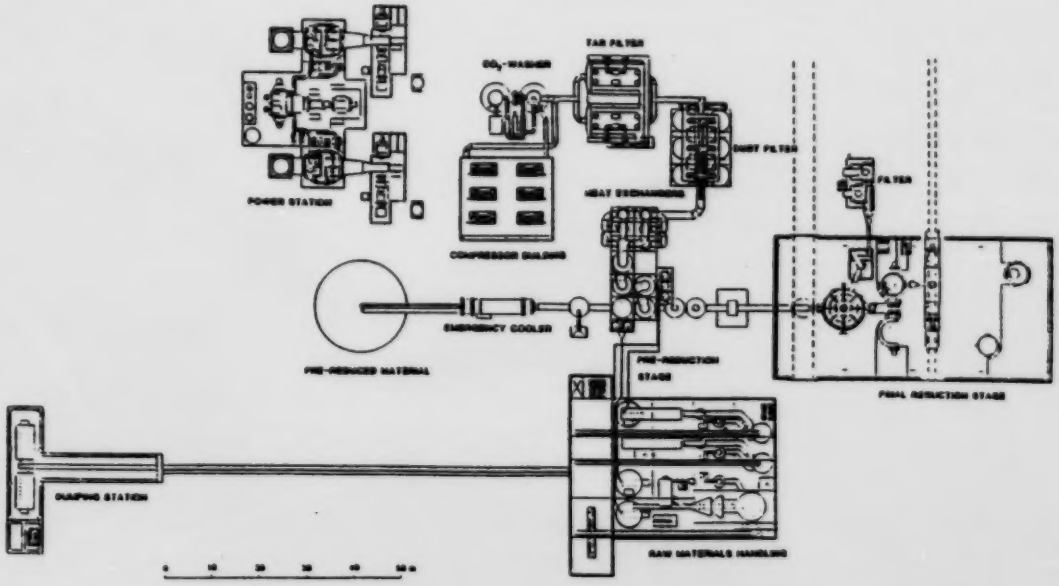
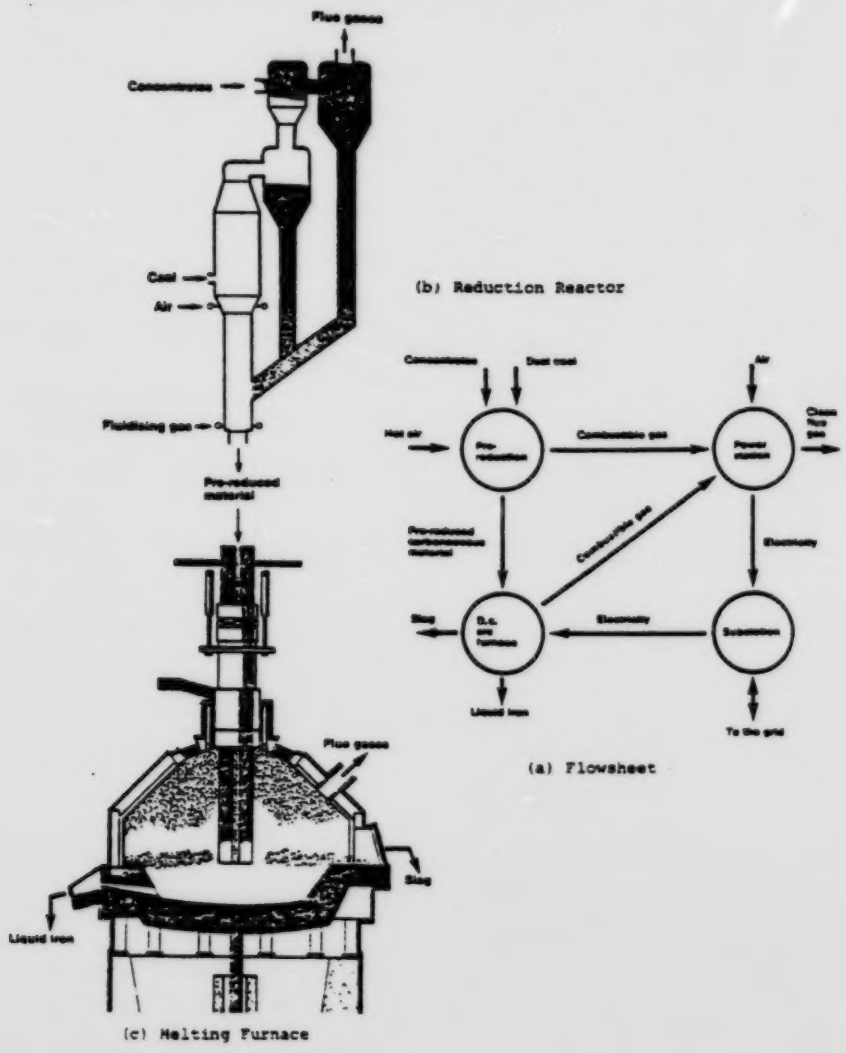


Figure 17 is a schematic of the Elred process. The reduction unit is a fast fluidized bed fed with dried fine ore, limestone and coal together with air (may be oxygen-enriched) for combustion, and cleaned recycled off-gas as a fluidizing gas. The reactor operates with a high level of particulate entrainment in the gas stream. These particles are captured in a series of cyclones and returned to the bed as a recirculating load which is very much greater than the material feed rate. The material leaving the reduction unit aims to be at 60 to 75 percent reduction.

The fluidized bed reduction unit is operated at a pressure of approximately 5 bar and a temperature of 950° to 1000°C.

Figure 17: Elred Process (Smith and Corbett, 1985)



Reduced material is discharged from the reduction reactor via depressurization vessels and is cooled to 800° to 850°C before being passed to the electric furnace by a bucket elevator. The reduced material passes down the center of a single hollow Soderberg electrode, at the tip of which a high power density dc plasma arc is struck onto the molten metal bath surface and submerged in the furnace slag.

The molten iron which collects in the furnace is tapped periodically using blast furnace taphole technology, and slag is flushed continuously through a separate slag notch.

The off-gas from the reduction unit, calorific value 3.5 to 5.0 MJ/Nm^3, is cooled to approximately 300°C and passed through a hot bag filter at this temperature to prevent tar condensation from blinding the filter bags. It is then cooled further to around ambient temperature and passed through a tar precipitator to give a total solids loading of <10 mg/Nm^3. The stream is then divided into two, with about one-third passing to a carbon dioxide scrubbing unit before returning to the fluidized bed reactor as fluidizing and coal transport gas. The other two-thirds goes to the power station as fuel for electricity generation. The energy for the CO_2 scrubber is obtained via a heat exchanger on the hot reduction gas stream leaving the fluidized bed reactor.

The electricity generated exceeds the internal process requirements, and this excess is available for export either to adjacent works units or to the public utility grid.

Status:

- 1979/1980 - the process was considered ready for marketing and a worldwide effort was mounted.
- Timing was bad - worldwide recession.
- Stora then withdrew from the development and, indeed, from the steel business leaving ASEA as the sole proprietor of the process.
- 1983 - decision was taken to cease all development activity and maintain only a low level of marketing activity.
- For serious clients, ASEA would undertake energy and economic feasibility studies using existing mathematical models; reduction plant is mothballed but could be reactivated for tests; pilot melting furnace at Domnarvets has been demolished and so no facilities exist for final melting test.
- The cooperation with Lurgi lapsed sometime in 1983 to 1985 and has not been renewed.
- It is considered unlikely that a commercial Elred plant will be built.

Potential Contacts:

ASEA

References:

- R. B. Smith and M. J. Corbett, "Coal-Based Ironmaking - A Study", 1985, ECSC-Sponsored Research Project, Agreement No. EC1-1274-B7240-84UK, BSC Ref: FR 158-3/852, September.

A 10. FOSTER WHEELER - TETRONIX PROCESS

Developer:

Foster Wheeler
Tetronix

Purpose:

To smelt ore fines using fine coal and plasma.

Principle:

This process is based on a rotating transferred arc to smelt ore and coal fines.

Status:

- Very little information available.
- Smith and Corbett rejected it as being inappropriate to the European economic scene since its main energy input is electricity.
- This is likely the Tetronix process which has been tested to process EAF dust.

Potential Contacts:

None.

References:

- R. B. Smith and M. J. Corbett, "Coal-Based Ironmaking - A Study", 1985. ECSC-Sponsored Research Project, Agreement No. EC1-1274-B7240-84UK, BSC Ref: FR 158-3/852, September.

A 11. HIsmelt PROCESS (High Intensity Smelting Process)

Developer:

CRA Ltd, Melbourne Australia (owners of Hamersley Iron Company)
Klöckner Stahlwerke
CSIRO (an Australian research organization)
Midrex Corp (USA) - owned by Kobe Steel Corp

The process development was initiated in the early 1980s by CRA in partnership with the West German steelmaker Klöckner Stahlwerke, with major involvement by the CSIRO. CRA's and Klöckner's interests were restructured in 1987, with the result that CRA acquired 100 percent interest in the process. CRA then sought a new partner with the appropriate expertise to help further the development program. Midrex, USA, owned by Kobe Steel Corp., acquired an equal ownership with CRA in the new technology. The new 50:50 joint venture is called HIsmelt Corporation Pty Ltd.

Purpose:

Low cost production of pig iron (hot metal) and steel.

CRA's subsidiary, Hamersley Iron, has obligations under two Acts of the Western Australia parliament under whose aegis the Company operates. Under the Acts, the Hamersley Range Agreement and the Mt Bruce Agreement, Hamersley is obliged "to establish the processing of its iron ore into an added value state" and "to establish a plant to produce steel in stages up to one million tonnes per annum".

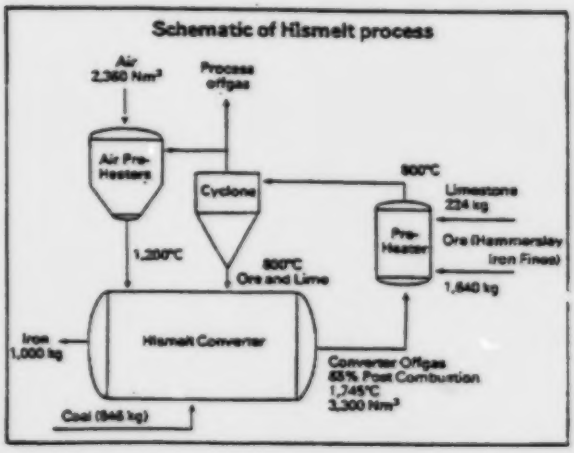
Principles:

The HIsmelt process is based on the direct injection of the fine iron ore, together with coal, into a closed molten bath reactor. The gas produced in the reduction process is burned in such a way as to return most of the heat so generated back to the bath. The process flowsheet is shown in Figure 18.

Status:

- Midrex joined CRA as an equal partner in 1989.
- Development activities of the joint venture are expected to span some three years.
- Engineering is expected to be advanced sufficiently to commence construction of a larger-scale pilot plant during 1990/91.
- The location of the pilot plant has yet to be formally announced but, if it is built in Western Australia, it will go some way towards enabling Hamersley Iron to fulfill its obligations to the state. The most likely location is at BHP's Kwinana steel plant which has been shut down.
- Davy McKee has been retained to advise on the design and construction of the plant.
- R&D was completed at the CRA-Klöckner research facilities in Sulzbach Rosenberg, FRG, in June 1990.

Figure 18: Schematic of HIsmelt Process (MBM, 1989)



A variation on this flowsheet is the replacement of the ore preheater with an ore reduction (to FeO) unit.

Contact:

Mr. Richard Rusden, Managing Director - Klöckner Stahlforschung
(name received from A. Hauck, Klöckner)
Dr. Donald K. Philips, General Manager - Process Metallurgy

References:

- Metal Bulletin Monthly (MBM), May 1989, p 81 (news item).
- Skillings Mining Review, April 15, 1989, p 21 (news item).
- Direct from Midrex, 2nd Qtr, 1989, Vol 14, No. 3 (news item).
- Metal Bulletin Monthly, March 4, 1989, p 23 (news item).
- K. Brotzmann, "New Concepts and Methods for Iron and Steel Production", 1987, Howe Memorial Lecture, Steelmaking Conference Proceedings, AIME/ISS, Pittsburgh, PA, Vol 70, pp 3 to 12.
- J. A. Innes et al, "Direct Smelting of Iron Ore in a Liquid Iron Bath - The HIsmelt Process", 1988, Proceedings, 7th Process Technology Conference, AIME/ISS, Toronto, Canada, April 17 to 20, pp 225 to 231.
- K. Brotzmann, "Smelting Reduction in Iron Baths", 1990, Steel Research 60, Verlag Stahleisen mbH, No. 3 + 4, pp 110 to 112.

A 11(a): KSG PROCESS (Forerunner to HIsmelt)

Developer:

Klöckner Stahlforschung

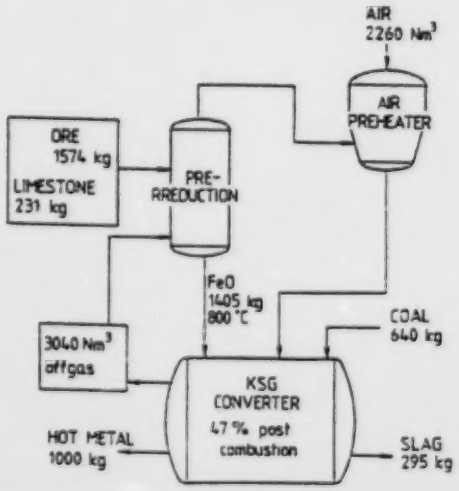
Purpose:

To develop a process which will produce hot metal from ore fines and fine coal directly.

Principles:

Other processes of this type, i.e. partial reduction followed by in-bath smelting, tend to favor the BOF-type vessel as the smelter unit. Klöckner's process uses a vessel of a different design which maximizes the surface of the bath (the actions of interest in this process occur primarily at the surface of the bath). The larger surface provides for improved mixing of gases and slag-making materials, and improved transfer of the energy derived from the post-combustion reaction (Figure 19).

Figure 19: Schematic of the Klöckner KSG Process (Brotzmann, 1987)



Air, not pure oxygen, is used in the KSG process. The large volume of hot off-gas can be utilized to preheat the incoming air to achieve economies in energy consumption; the cost of generating pure oxygen is avoided but there is increased cost for cleaning the much larger volumes of waste gas.

The Klöckner program concentrated on obtaining high (>45 percent) post-combustion levels. At this level, coal consumption (predicted) is decreased to about 640 kg/thm with partially reduced (to FeO) ore fines.

The energy available in the off-gas is sufficient to preheat the incoming air to the necessary 1200°C temperature. No surplus energy is obtained, so that no energy has to be transferred to interconnected systems, i.e. there is no value to the export gas.

Status:

- In the pilot plant operation, investigation centered on the conditions under which high post-combustion levels with a high thermal efficiency can be achieved. A number of different coal grades were tested.
- This process has been superseded by the HIsmelt process and Klöckner are no longer involved.

Potential Contacts:

K. Brotzmann	General Manager - Klöckner Stahlforschung
H. G. Fassbinder	Manager, Process Engineering
V. Pawliska	Senior Engineer, International Development
J. P. Moodie	CRA/Klöckner Joint Venture
R. C. Rusden	General Manager, Engineering

References:

- K. Brotzmann, "New Concepts and Methods for Iron and Steel Production", 1987, Howe Memorial Lecture, Steelmaking Conference Proceedings, ISS-AIME, Pittsburgh, PA, Vol 70, pp 3 to 12.
- "Future Steelmaking", 1988, Report of AISI Task Force on Direct Steelmaking, March.

A 12. INRED PROCESS

Developer:

The Boliden Group of Companies:

- Boliden AB, Stockholm
- Boliden Bergsöe AB, Landskrona
- Boliden Metall AB, Skelleftehamn

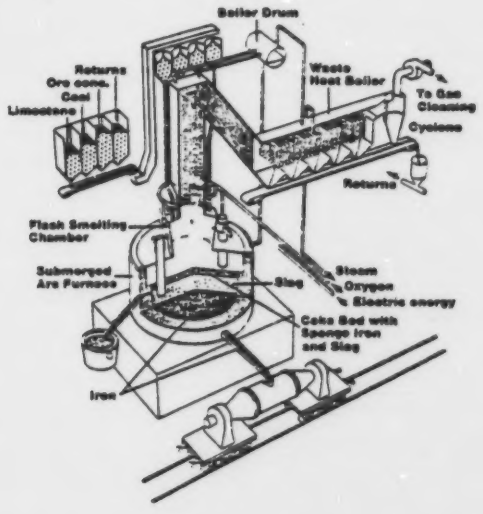
Purpose:

Initially to smelt fine iron-bearing materials, particularly fine pyrites cinder containing lead, zinc, arsenic and sulfur - a by-product of Boliden Keuri's sulfuric acid manufacturing operation at Helsingborg - to overcome a (foreseen) disposal problem. Then during development, the process was noted to have wider applicability in the smelting of fine iron ores as a primary ironmaking process in its own right.

Principles:

The Inred process is basically an electric melting/coal-based reduction process in which the metallurgical process operations are carried out in a single reaction unit which consists of a flash smelting chamber immediately above, and directly linked to, an electric melting furnace (Figure 20).

Figure 20: Inred Process (Smith and Corbett, 1985)



Pre-mixed fine ore, coal and fluxes are fed into the flash smelting chamber via injection lances, together with primary oxygen; secondary and tertiary oxygen jets are also introduced to promote a swirling action. Control of the flow rates and trajectories of these various components is aimed at ensuring rapid and essentially complete combustion of the furnace gases, giving temperatures of around 1900°C. Superheated liquid FeO, together with some char, falls into the electric furnace where final reduction to metallic iron takes place. The heat for this final reduction is supplied from three sources:

- electric heating by submerged arcs,
- superheat of materials falling from the flash smelter, and
- radiation from the combustion zone of the flash smelter.

Additional reductant in the form of coarse coal is fed into the electric furnace at selected positions. The process is designed to operate at or near ambient pressure.

Status:

- Four experimental campaigns were carried out in the demonstration plant. Production rates were 3 to 6 t/h; output in the last two campaigns exceeded 700 t hot metal in each campaign.
- Boliden Inred Co was established to market the process; subsidiary companies overseas were Inred Iron Inc (USA) and Inred (Canada) Inc.
- Combustion Engineering took a financial interest in Boliden Inred.
- In 1981 Ivaco Inc, Canada, purchased an option on a plant to be activated when the technical development program was completed.
- Ivaco's option was later extended to cover a plant in the USA.
- The last test campaign on the demonstration plant took place in May 1984 and Boliden Inred considered that a further three campaigns over a period of 1-1/2 to 2 years would be needed to take the development to a stage where construction of a commercial-scale plant would be feasible.
- Boliden Inred had no success in finding a partner among steel producers (discussions held in Europe, Japan and USA) or with the Steel Authority of India.
- The disposal of pyrite cinder is no longer viewed as a viable justification to carry on the development.
- Further effort is doubtful; Boliden Inred cannot find a partner and they are not prepared to proceed alone.

Potential Contacts:

None.

Reference:

- R. B. Smith and M. J. Corbett, "Coal-Based Ironmaking - A Study", 1985, ECSC-Sponsored Research Project, Agreement No. EC1-1274-B7240-84UK, BSC Ref: FR 158-3/852, September.

A 13. KHD PROCESS

Developer:

KHD Humboldt Wedag AG, Cologne, FRG

Purpose:

The development of a new smelting-reduction process based on molten iron puregas (MIP) technology.

Principles:

On the basis of the MIP development, combined with process engineering experience, KHD Humboldt Wedag AG investigated several innovative process concepts for primary ironmaking technology. The present concept of the KHD smelting-reduction process is shown in Figures 21 and 22.

Figure 21: Flowsheet of the KHD Smelting-Reduction Process (Barin et al, 1989)

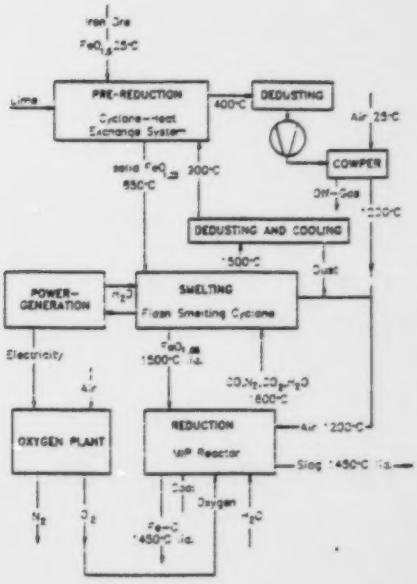
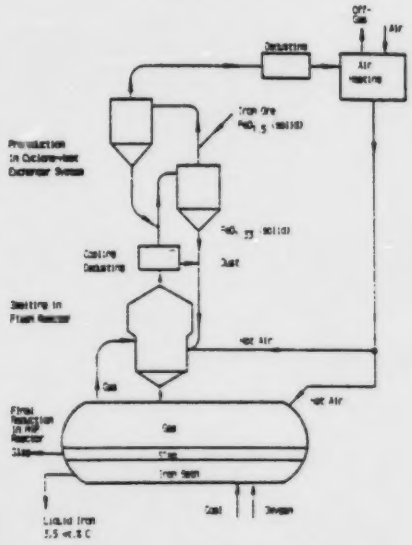


Figure 22: Schematic Diagram of Three-Stage KHD Process (Barin et al, 1989)



The KHD process is a 3-stage smelting-reduction process:

- stage 1: the ore is preheated up to 850°C and reduced from hematite to magnetite by recirculation of the fine ore in a cyclone/heat exchanger system,
- stage 2: the pretreated material is melted in the flash smelter by combustion of the reducing gases with preheated air, which is introduced in jets to promote an intense swirling action. A liquid iron/oxygen melt of composition $FeO_{1.06}$ is formed,

- stage 3: the final reduction of the partially reduced, melted and superheated ore to metallic iron takes place at about 1450°C in the (MIP) gasifier.

Electricity required for oxygen separation is generated from waste heat.

Depending upon the coal quality, about 600 kg fine coal/thm are consumed in the process, if no surplus gas is required. In this case, the top gas is burned completely to preheat the combustion air.

Status:

- MIP process has been tested at MEFOS, Luleå, Sweden, in a gasifier having a capacity of 20 tonnes of liquid iron.
- No indication of further work on this process.
  [Note: any process which has to deal with liquid FeO has a major problem with containment.]

Potential Contacts:

Prof. Dr.-Ing. I. Barin - Research & Development
Dr.-Ing. M. Lemperle KHD Humboldt Wedag AG
Dr.-Ing. M. Modigell Cologne, FRG

References:

- I. Barin, M. Lemperle, and M. Modigell, "Smelting Reduction of Iron Ore", 1989, Steel Research 60, Verlag Stahleisen mbH, No. 3 + 4, pp 120 and 121.

A 14. KOBE PROCESS

Developer:

Kobe Steel Ltd. (Japan) and the Midrex Corporation (USA) which is owned by Kobe.

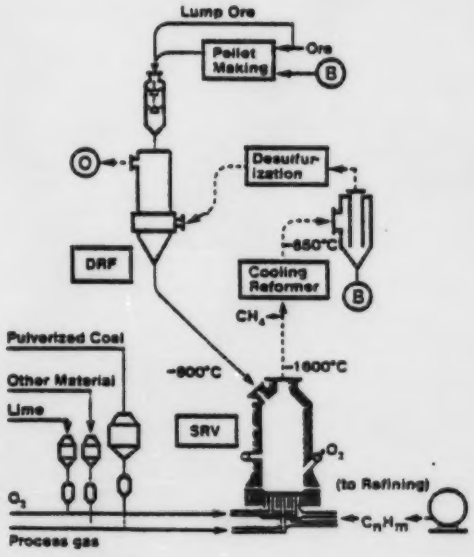
Purpose:

To develop a coal-based ironmaking process for the 1990s - from the two aspects of steel producer and engineering company.

Principles:

The present Kobe concept (Figure 23) is based on converter technology, for melting of reduced iron ore, and the Midrex shaft furnace for direct reduction. The melting vessel utilizes bottom tuyeres to inject coal and oxygen into the molten iron bath and side tuyeres are provided above the melt for in-bath combustion. Off-gases from the melter are cooled to reduction temperature by indirect cooling or by reforming of natural gas. The direct reduction shaft can be operated with or without recycled scrubbed top gas. DRI is charged hot into the melting vessel (which presumably operates on the hot liquid heel principle).

Figure 23: The Kobe Process
(Smith and Corbett, 1985)



Status:

- Development of the process was in an early stage in 1985, with efforts being concentrated on mathematical simulation of material and energy balances and economic calculations.
- Experimental work to 1985 was very limited (a small number of scrap-melting experiments in a 500 kg converter).
- Plans indicated in 1985 were:
  - 1986/1987: flowsheet studies and small pilot plant experimentations
  - 1986/1989: design, construct, and operate a pilot plant
  - 1990: to be able to specify a demonstration plant.

  It was not clear whether these plans had been fully approved.
- Work on this process appears to have been suspended in favor of collaborating on the DIOS project and, through Midrex, on the HIsmelt process.

Potential Contacts:

Dr. S. Ohta, General Manager, Iron and Steel Research Laboratories

References:

- R. B. Smith and M. J. Corbett, "Coal-Based Ironmaking - A Study", 1985, ECSC-Sponsored Research Project, Agreement No. EC1-1274-B7240-84UK, BSC Ref: FR 158-3/852, September.
- "Future Steelmaking", 1989, Report of AISI Task Force on Direct Steelmaking, March.

A 15. LB PROCESS

Developer:

McMaster University, Hamilton, Ontario, Canada

Purpose:

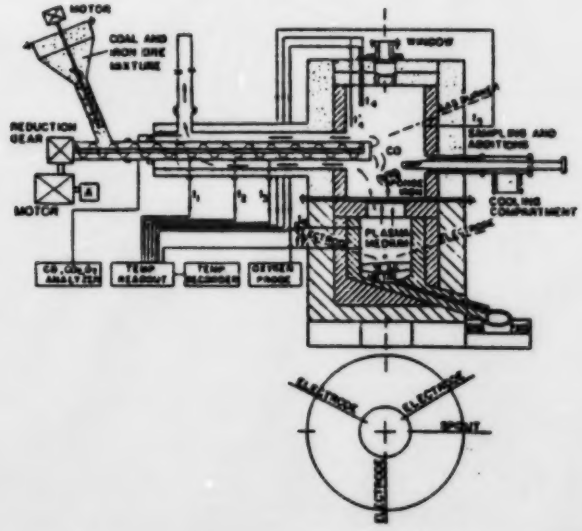
A new ironmaking technology with the following features:

- a liquid metal product,
- flexible production level,
- low capital cost,
- low and stable production costs, and
- advantages in environmental quality control and automation.

Principles:

Figure 24 shows a cross section of the LB furnace. Screw feeders move the charge material, a blend of fine coal and iron ore concentrate, through refractory reaction tubes. The coal/ore mixtures are moved from the cold end of the tube to become sponge iron which drops off at the hot end into the melting zone. The steel screw is cooled by the reacting mixture. Transit time through the reaction tubes is about 10 minutes.

Figure 24: Cross Section of the LB Furnace (Lu et al, 1986)



The melting zone is heated by plasma which is generated with argon flowing through the three hollow electrodes.

The hot gases generated in the reduction tubes are burned in the upper chamber of the LB furnace by means of air introduced at ambient temperature. The heat generated is used for preheating, carbonization, and reduction.

The cold end of the reaction tube is sealed so that all generated gases exit at the hot end with a linear velocity of a few meters a second, depending on the overall reaction rate and the temperature of the chamber. The flow of the exit gas, which is reducing with respect to the wustite/iron equilibrium at actual temperatures, appears to be strong enough and sufficiently well distributed to protect the sponge iron from reoxidation by the strongly oxidizing flame located a short distance downstream.

Status:

- Process proven in laboratory-scale LB furnace.
- Plans for a large LB furnace (1986), capacity 240 kg/hr hot metal, did not materialize.
- LB furnace (laboratory-scale) has also been tested as a coke producer and for the processing of waste oxides such as BOF dust (eliminate Zn and Pb oxides through reduction/gasification).

Contact:

- Dr. W-K Lu, Stelco Professor of Metallurgy, McMaster University, Hamilton, Ontario, Canada.

References:

- W-K Lu et al, "The LB Furnace for Smelting Reduction of Iron Ores", 1986, Proceedings, 5th International Iron and Steel Congress, AIME/ISS, Washington, DC, April 6 to 9, pp 1065 to 1075.
- C. Bryk and W-K Lu, "Continuous Reduction of Iron Ore with Coal in an Electrically Heated Furnace", 1986, Canadian Metallurgical Quarterly, July to September, Vol 25, No. 3, pp 241 to 246.
- C. Bryk and W-K Lu, "A New Alternative for Iron and Steelmaking Technology Based on Coal and Plasma", 1988, Arch Metal 33 (2), pp 163 to 177.
- W-K Lu and H. Y. Gou, "The Development of a Smelting Reduction Process", 1986, Proceedings Shenyang International Symposium on Smelting Reduction, September 3 to 5.
- H. Y. Gou and W-K Lu, "Transport Phenomena in the Combustion Chamber of the LB Furnace", 1988, Proceedings, 7th Process Technology Conference, AIME/ISS, Toronto, Canada. April 17 to 20, pp 271 to 281.
- X. Yao, Y. Zhao, and W-K Lu, "A Mathematical Model of Heat Transfer in LB Furnace", 1988, Proceedings, 7th Process Technology Conference, AIME/ISS, Toronto, Canada, May 17 to 20, pp 65 to 73.

A 16. NIPPON STEEL PROCESS

Developer:

Nippon Steel Corporation

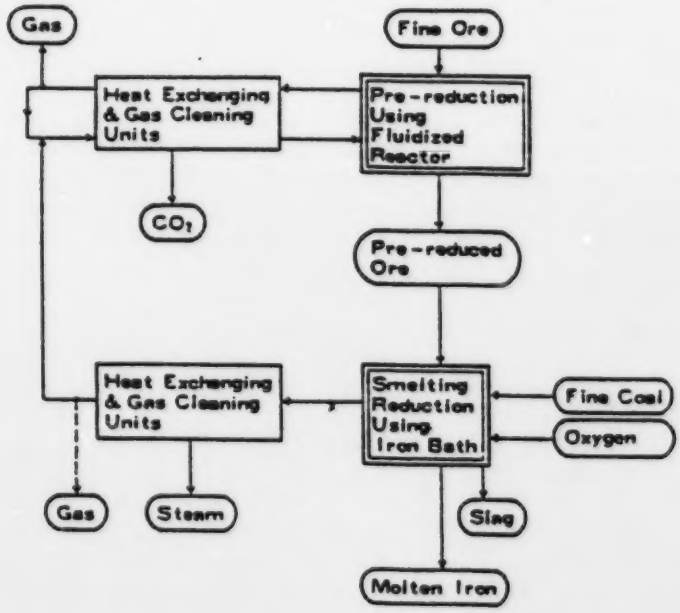
Purpose:

To develop a more economical method of processing iron ore which is capable of replacing or supplementing the blast furnace in an integrated iron and steel works.

Principles:

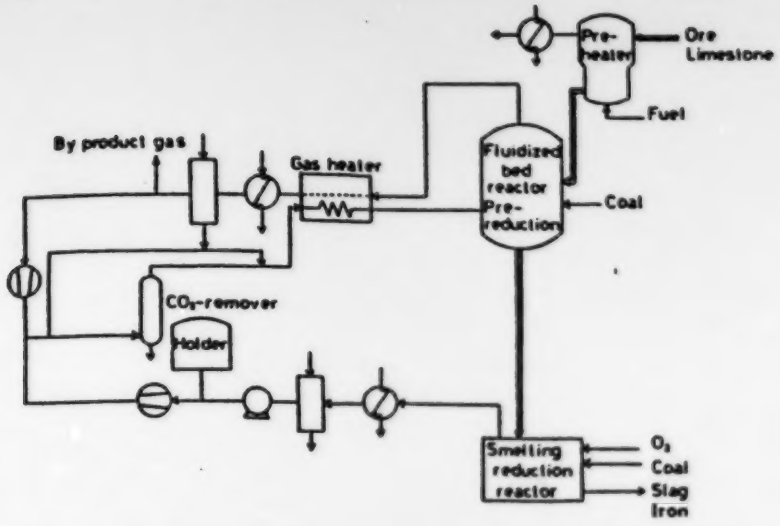
The basic concept of Nippon Steel's smelting-reduction process is shown in Figure 25.

Figure 25: Concept of Process Flow (Hayashi et al, 1986)



One example of the process flowsheet is given in Figure 26.

Figure 26: An Example of Process Flow Sheet (Hayashi et al, 1986)



- The combined blowing converter was selected as the basic design for the smelting reduction reactor. The aim was to utilize a thick slag layer to allow high levels of post-combustion.

- A prereduction furnace was added to reduce unit fuel consumption in the smelting reduction reactor by dividing the reducing load and, at the same time, effectively utilizing the reducing gas generated by the smelting reduction reactor. A fast fluidized bed reactor was selected; both carbonaceous material and iron ore are charged to it. The carbonaceous material helps to keep the iron ore particles from sintering together and in controlling the composition and temperature of the gas in the reactor by the partial oxidation of the carbonaceous material.

- The iron ore fines (pulverized iron ore) are reduced about 50 percent in the fluidized bed.

- The partially reduced (hot) iron ore, coal and oxygen are charged into the bath-type smelting-reduction reactor, where the partially reduced iron ore is smelted, producing iron (hot metal) and gas. The heat required for the smelting-reduction reactor is supplied by the partial combustion of coal and the post-combustion of part of the generated CO and H_2 gas.

- The gas generated in the smelting-reduction reactor passes through a waste heat boiler to recover the sensible heat as high-pressure steam. Its pressure is then increased, at room temperature, by a compressor. This gas joins the circulating gas from the prereduction unit, passes through a CO_2 removal unit, is heated via a heat exchanger by the exhaust gas from the prereduction unit, and enters the prereduction unit.

- Following the heat exchanger, low-pressure steam is recovered from the exhaust gas from the prereduction unit using a waste heat boiler. Part of this exhaust then becomes the circulating gas (back to the prereduction reactor) while the remainder is sent downstream in the steelworks as export gas.

Status:

- Considerable paper studies and laboratory and small pilot-scale experiments and studies.
- Initial in-bath smelting reduction tests were associated with a national project, completed in 1988, to produce stainless steel by directly charging chromite ore to the steelmaking converter during refining. This process was successfully scaled up to a 170-tonne converter at Sakai Works.
- NSC essentially concentrating on collaboration in DIOS project.

Potential Contacts:

Yooichi Hayashi - Ironmaking Technology Lab
Masakazu Nakamura R&D Laboratories III
Maoki Tokumitsu Central R&D Bureau
Nippon Steel Corporation, Japan

References:

- Y. Hayashi et al, "Development of Smelting Reduction Process Using an Iron Bath", 1986, Proceedings, Process Technology Conference, AIME/ISS, Washington, DC, April, Vol 6, pp 1057 to 1064.
- R. B. Smith and M. J. Corbett, "Coal-Based Ironmaking - A Study", 1985, ECSC-Sponsored Research Project, Agreement No. EC1-1274-B7240-84UK, BSC Ref: FR 158-3/852, September.
- "NSC Uses Exhaust Gas of Melt-Reduction Furnace for Generator", 1989, Japan Metal Bulletin, January 19.
- "CRA Ltd/Midrex Corp. Form Joint Venture in Iron Smelting", 1989, Skillings Mining Review, April 15, p 21.
- M. Tokumitsu et al,"Development of Smelting Reduction Process Using an Iron Bath - Bench-Scale Experiments", 1988, Proceedings, 7th Process Technology Conference, AIME/ISS, Toronto, Canada, April 17 to 20, pp 99 to 107.
- H. Hirata, "Development of Smelting Reduction Process with a Thick Slag Layer", 1990, International Symposium/Workshop on Future Ironmaking Processes, Steltech, Hamilton, Canada, June 14 and 15.
- T. Ibaraki, "Development of Smelting Reduction of Iron Ore - An Approach to Commercial Ironmaking", 1990, Proceedings, Ironmaking Conference, AIME/ISS, Detroit, MI, Vol 49, March 25 to 28, pp 631 to 638.

A 17. PLASMADUST

Developer:

SKF Steel Sweden

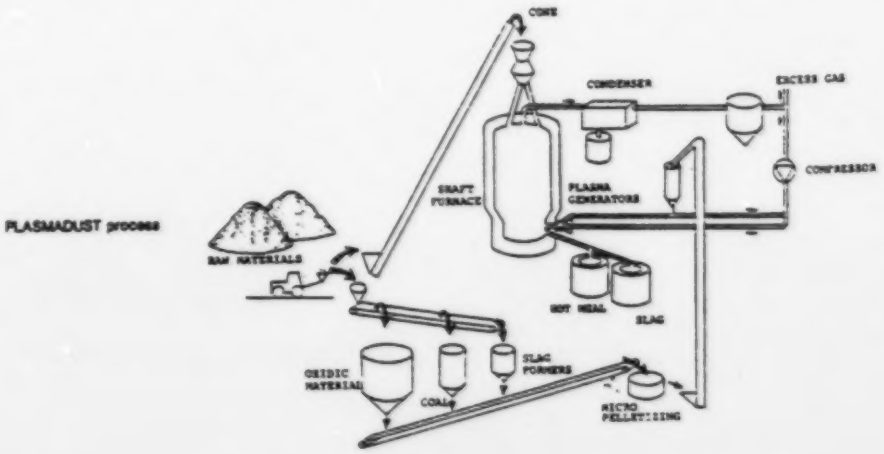
Purpose:

To recover metals from various waste oxides (off-shoot of Plasmasmelt Process).

Principles:

The Plasmadust process is outlined in Figure 27.

Figure 27: Plasmadust Process (Herlitz et al, 1984)



Waste oxide in the form of fine particles is pneumatically injected, along with coal powder, into the coke-filled shaft furnace provided with plasma generators. The metal oxides are reduced in a manner similar to the Plasmasmelt process.

Baghouse dusts from EAFs, as well as many other types of waste oxides, frequently contain considerable amounts of zinc and lead as metal oxides. These oxides are reduced in the coke-filled shaft, are vaporized and leave the top of the shaft furnace together with the gases. These metals are collected in a conventional condenser outside the furnace.

Status:

- In May 1982, SKF signed a contract with a Swedish Company, Scan Dust, to supply a turnkey Plasmadust plant with the capacity to process 70 000 t/yr dust. In 1984 this plant was being built at Landskrona, Sweden, for start-up in mid-year (1984).
- The plant at Landskrona processes the dusts from alloyed steel works across Western Europe.

Potential Contacts:

Sven O. Santen - SKF Plasma Technologies, AB.

References:

- H. G. Herlitz et al, "A New Family of Reduction Processes Based on Plasma Technology", 1984, Iron and Steel Engineer, March, pp 39 to 44.
- R. B. Smith and M. J. Corbett, "Coal-Based Ironmaking - A Study", 1985, ECSC-Sponsored Research Project, Agreement No. EC1-1274-B7240-84UK, BSC Ref: FR 158-3/852, September.

A 18. PLASMASMELT

Developer:

SKF Steel, Sweden

Purpose:

The program's purpose was to develop new metallurgical processes that could be used economically on a smaller scale than "today's" methods. The objectives included lower energy requirements, better energy efficiency, wider energy flexibility, and reduced environmental impact.

Principles:

The new processes were all based on the use of plasma technology and included:

- Plasmasmelt
- Plasmared (Direct Reduction)
- Plasmadust
- Plasmachrome, and
- Plasmascrap

Plasmasmelt (Figures 28 and 29) is an integrated smelting-reduction process based on a coke bed melting unit and a fluidized bed reduction unit. Hot DRI and reducing gases are injected into the melting unit with the reducing gas being generated by reforming coal or possibly other hydrocarbon fuels with recycled melter off-gas in electrical plasma torches.

Figure 28: Plasmasmelt (Herlitz et al, 1984)

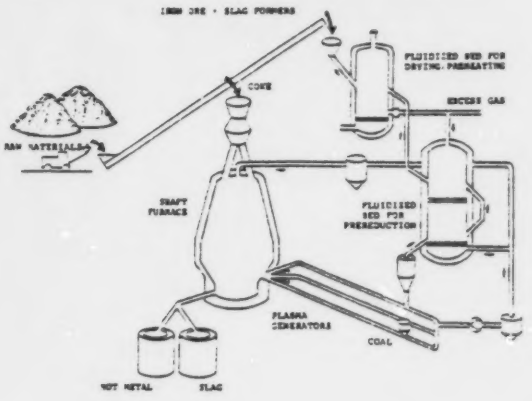
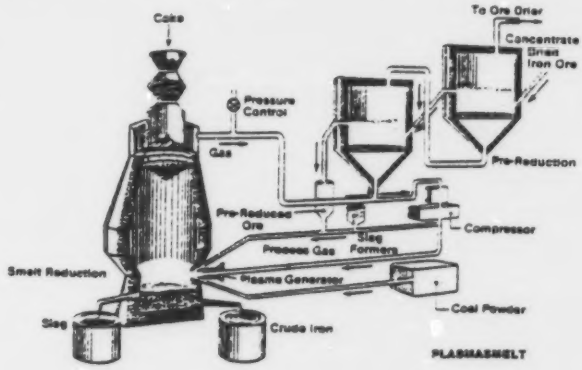


Figure 29: Plasmasmelt (Smith and Corbett, 1985)



Provision is also made for oxygen injection at the same point and so the heat source may be purely electrical, or a combination of electrical and combustion, or in principle pure combustion. The melting unit off-gas, after the recycling of a portion to provide process gas to the plasma torches, is passed to a reduction unit which incorporates two fluidized beds in series, producing partially metallized DRI which is injected into the melting zone of the melting reactor. A proportion of the spent reduction off-gases is burned to dry and preheat the ore fines which are the feedstock to the reduction reactor. The balance of the spent reducing gas is available as an export fuel.

Status:

- Melting step has been piloted extensively.
- The two-stage fluidized bed reduction step has been tested using five ores from Sweden and Brazil.
- By 1965 integrated testing of reduction and melting steps had not been tried.
- Emphasis seemed to shift to Scandust project.
- SKF sees the best prospects for this technology in areas other than ironmaking; a contract was received for a ferro-chrome plant, with a capacity of 10 to 12 t/hr, to be located at Malmo in southern Sweden; site preparation commenced in 1985.
- Discussions were reported to be under way in 1985 for other plasmadust plants and, also, on plasma reforming for direct reduction.
- Little, if anything, seems to be happening, re the spreading of this technology, in 1990.

Potential Contacts:

Hans G. Herlitz	Manager Engineering - SKF Steel Inc., Avon, Conn (1984)
Borje Johansson	Senior Research Metallurgist - Plasma Technology (1984)
Sven O. Santen	Manager, Plasma Technology - SKF Steel Engineering AB, Hofors, Sweden (1984) (SKF Plasma Technologies, AB - 1988)
J. Feinman	SKF Plasma Technologies, AB (1988) (J. Feinman and Associates Inc - 1987)

References:

- H. G. Herlitz et al, "A New Family of Reduction Processes Based on Plasma Technology", 1984, Iron and Steel Engineer, March, pp 39 to 44.
- R. B. Smith and M. J. Corbett, "Coal-Based Ironmaking - A Study", 1985, ECSC-Sponsored Research Project, Agreement No. EC1-1274-B7240-84UK, BSC Ref: FR 158-3/852, September.
- J. O. Edström and J. Ma, "Influence of the Type of Coal on Energy Consumption in Shaft Furnace Smelting Reduction Processes", 1989, Scand J. Metallurgy, 18, pp 105 to 112.

A 18(a). VARIATIONS ON PLASMASMELT

Plasma Chrome Process

Product:

Ferrochrome (high carbon)

Process:

Essentially as for Plasmasmelt but, since chromium oxides are not subject to gas reduction, no reduction step is used. The chromite (concentrate or fines) is injected, together with coal powder, directly into the shaft furnace.

Plasmaoxygen Process

Product:

Hot Metal

Process:

Plasmasmelt process modified to use oxygen to decrease the consumption of electricity.

Status:

Proposed by SKF (from 1989 paper).

Coaloxygen Process

Product:

Hot Metal

Process:

Plasmasmelt process modified to provide all the energy by burning coal, besides using some coke.

Status:

Being considered by SKF (from 1989 paper).

A 19. SUMITOMO SC PROCESS

Developer:

Sumitomo Metal Industries Ltd

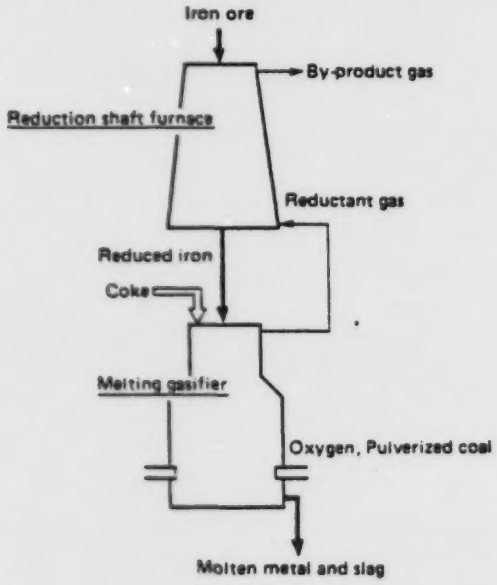
Purpose:

Develop a new ironmaking process with productivity and thermal efficiency as good as that of the blast furnace but using low quality raw materials.

Principles:

In the melter-gasifier, pure oxygen and pulverized coal are injected through tuyeres into a coke packed bed to produce high temperature gas. The gas melts the reduced ore which is hot charged through the top of the melter-gasifier. The recovered off-gas from the melter-gasifier is then used to reduce the ore in the shaft furnace. The process is shown schematically in Figure 30.

Figure 30: SC Process (Hatano et al, 1985)



In the reduction shaft furnace, ore is counter-currently reduced by the off-gas from the melter-gasifier. The reduced ore is transported hot to the melter-gasifier.

Two Notes:

- "low grade" coke is used in the melter-gasifier,
- ore feed is lump ore, sinter or pellets.

Status:

- Pilot plant work essentially completed except for some refinements to their process understanding.
- 1985: planning and designing the next generation demonstration plant.
- 1986: a 100 t/day demonstration plant is "under consideration".
- 1987: commercial plant designed schematically.
- The demonstration plant was not built because of high cost and no partners to share it.
- Work essentially shelved in favor of cooperative work on DIOS project.

Potential Contacts:

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Fumio Nakamura**	
Takao Maeda**	
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Teruhisa Shimoda	SRE, Ironmaking Laboratory Central Research Laboratories

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** Head Office, Iron and Steel Technical Development Department, Sumitomo Metal Industries Ltd., Higashi-ku, Osaka 541.

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A 20. KAWASAKI FINE ORE SMELTING-REDUCTION PROCESS (XR PROCESS)*

Developer:

Kawasaki Steel Corporation

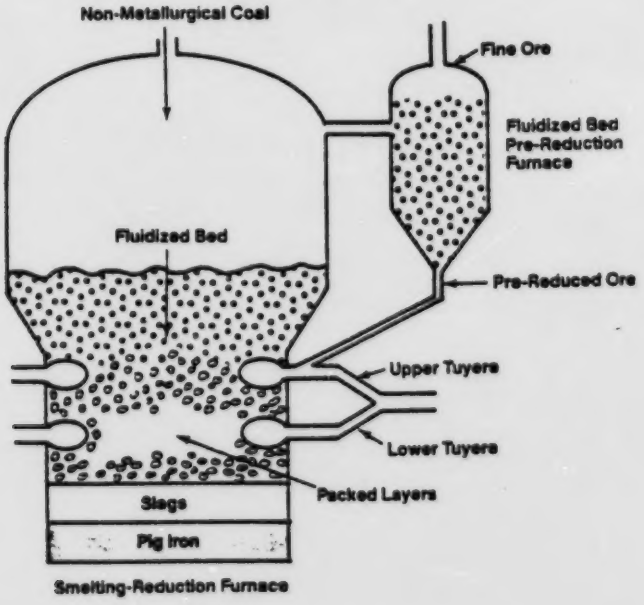
Purpose:

To reduce investment and operating costs in the production of hot metal.

Principles:

Figure 31 is a schematic representation of the XR process.

Figure 31: Kawasaki's XR Process (33MP, 1987)



Lumpy or fine noncoking coal is poured into the top of the main shaft furnace, while the auxiliary furnace is charged with fine ore, also from the top. The main furnace is equipped with a dual-tuyere system through which a mixture of hot blast and oxygen is blown.

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* Excellent Kawasaki Smelting Reduction Process
EKSR = XR

The fine ore is reduced to 50 to 70 percent as it passes through the auxiliary furnace's fluidized bed. This partially reduced ore, together with pulverized fluxes, is injected into the main furnace via the upper tuyeres.

The coal burns as it descends through the fluidized bed of the main chamber. It gets stacked up in packed layers at the furnace bottom. The carbon monoxide released, and the heat generated, drive chemico-metallurgical reactions to complete the reduction of the fine ore and separate the iron from the impurities through the smelting process. Molten iron and slag are tapped periodically.

The off-gas from the main furnace is directed through the auxiliary furnace to heat and partially reduce the ore fines.

Status:

- Ref 5: May 1989 Iron and Steelmaker, Vol 16, No. 5, "The Chiba Works of Kawasaki Steel Corporation (KSC) recently finished combining its fluidized bed pre-reduction furnace (0.7 m diameter x 7.3 m high) directly to a smelting reduction furnace".
- Study began in 1972; pilot plant was built in 1983.
- Plans were to have a 10-tonnes/day pilot plant installed in Chiba Works for thorough R&D prior to commercialization phase, utilizing a 500 000 tonnes/yr furnace, in five years (from 1987).
- Will continue to develop the XR process for both ironmaking and ferrochrome production even while collaborating on the DIOS project. Pilot plant work will focus on ironmaking applications.

Potential Contacts:

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Masahiko Sato
Kyoji Nakanishi

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- H. Itaya et al, "Ferroalloy Production by Smelting Reduction Process with Coke-Packed Bed", 1989, Kawasaki Steel Giho, Vol 21, No. 3.

B 1. AISI DIRECT STEELMAKING

Developer:

American Iron and Steel Institute (AISI) with approximately 70 percent funding from USA Department of Energy (DOE).

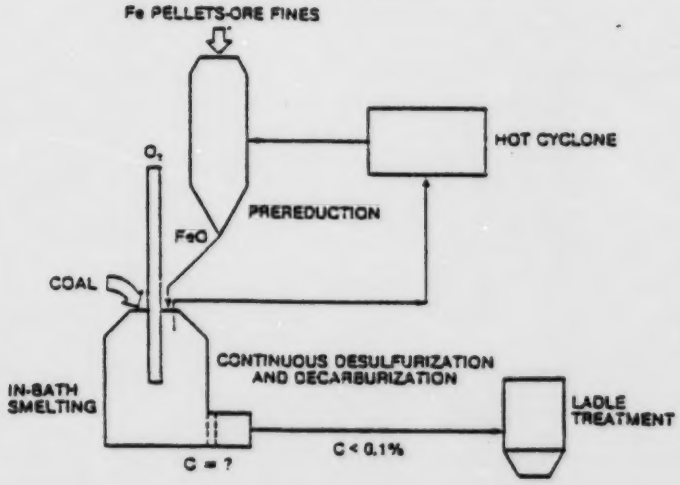
Purpose:

To develop a new process that will replace the coke ovens, sinter plant, pellet plant, blast furnace and steelmaking furnaces which form the standard process route to steel production in a modern integrated steel plant.

Principles:

As the process is currently envisioned (Figure 32), coal and reduced iron ore are charged into a vessel already containing a bath of liquid iron. The mixture is injected with oxygen and the resulting heat facilitates the conversion of the ore to high-carbon liquid steel. Further treatment with oxygen reduces the carbon content to levels required in the finished steel product. Carbon monoxide given off in the process is burned inside the vessel to preheat the ore and maintain a self-sustaining heat balance. The ultimate aim is to make the smelting reduction into a continuous steelmaking process, as opposed to the batch processing required in today's ironmaking and steelmaking processes.

Figure 32: Schematic Diagram of the Proposed Direct Steelmaking Route (McAloon, 1988)



Status:

- A pilot plant for studying the smelting reduction process has been constructed near Pittsburgh at a facility leased from USS at Universal. Design capacity is 120 tons a day. Engineering is by Hatch Associates. Start-up was scheduled for first quarter 1990 but was delayed until June.
- Critical experiments on scaleup of the process were conducted in the autumn of 1989 by the AISI team and Dofasco.
- Laboratory research program on critical issues is to be conducted in industrial research laboratories and universities. Carnegie Mellon University and MIT have undertaken a broad-based program on the study of the physical chemistry of the smelting-reduction process.
- McMaster and McGill Universities are conducting research on heat transfer in collaboration with Linde.
- Water modeling on continuous refining is in progress at US Steel and Carnegie Mellon University.
- HyLSA, Monterrey, Mexico, will conduct research and development on the partial reduction of iron ore pellets to wustite.
- The Project Board, Technical Advisory Committee, and Program Director are in place.
- DOE has agreed to finance the major portion of the effort; contract has been signed.
- Pilot plant construction was completed early in June 1990, with hot metal scheduled to be put through the system on June 14.

Potential Contacts:

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Mr. H. R. Pratt - USS

References:

- T. P. McAloon, "Direct Steelmaking Program Proposed for the United States", 1988, I&SM, July, pp 30 to 32.
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  - presentation by A. McLean to "Technology Update 1989".
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- "Future Steelmaking", 1988, AISI Task Force Report, March, Chairman, E. Aukrust, LTV Steel.
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B 2. IMIS PROCESS

Developer:

Institute Mexicano de Investigaciones Siderurgicas (IMIS), Mexico

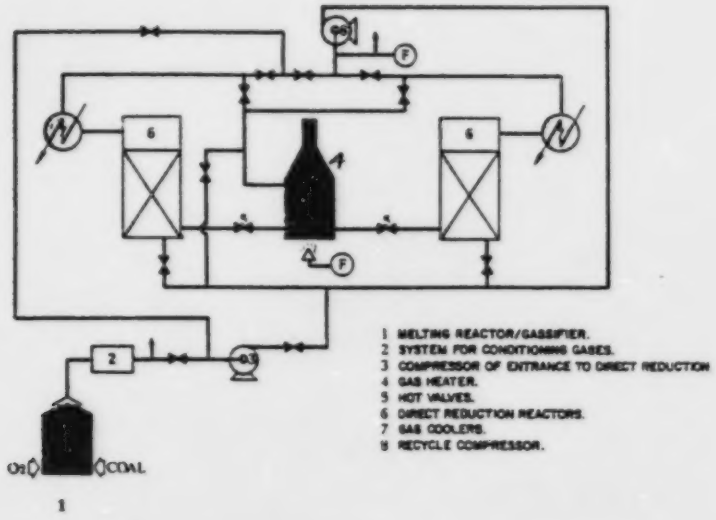
Purpose:

A method for the production of steel that would use the necessary energy in a more direct and efficient manner.

Principles:

Figure 33 describes the IMIS process.

Figure 33: Flow Diagram of the Process According to the Experimental Equipment (Navarro, 1987)



The main input of energy to the process is in the form of coal and oxygen through the bottom of the melting reactor/gasifier (BOF converter). In some cases, this may be the only input of energy to the system; the quantity of coal injected is that necessary to carry out the operations of melting and refining of steel in the converter and, therefore, it is not intended to inject coal with the purpose of obtaining a reduction gas. Thus, the quantity of gas per tonne of liquid steel produced is the minimum possible, and it will depend on the charge to the converter and the coal to be used (its volatile matter content, ash content, and fixed carbon), among other things.

The process is initiated by charging an adequate quantity of liquid metal into the converter so as to allow the proper ignition of the injected coal. When the carbon content of the bath is <2.0 percent, a reducing stage is initiated; when it is between 2.0 and about 4.0 percent, an oxidizing stage is initiated. The process continues by reducing and oxidizing alternately, in complete cycles. After several cycles have been completed, which allows the melting of solid charges (DRI by batch addition),

the weight of liquid steel is sufficient for tapping, while leaving a molten heel in the vessel. This hot heel serves as the ignition metal for the next series of cycles.

During the reducing periods, a reducing gas having a composition (H_2+CO) ≥80 percent is obtained. It can be used directly, or indirectly through gas-holders, in a direct reduction plant to produce direct reduced iron. The DRI is fed to the converter during the oxidizing periods, completing the cycle of steel production directly from iron ore.

From the gas generated per tonne of liquid steel, 630 Nm^3 will be needed to produce one tonne of sponge iron by direct reduction, this being the theoretical minimum considering an ore of 66.2 percent iron, 28.3 percent reducible oxygen, and an exhaust gas from the converter containing hydrogen plus carbon monoxide equal to 95 percent.

The gas is cleaned and cooled. The energy required to heat the reducing gas to reducing temperature increases the gas requirement to 1300 Nm^3/tonne sponge iron.

Excess gas, if sufficient in quantity, can be exported to other parts of the plant as fuel gas or used to produce electricity.

Status:

- In 1986, a pilot plant based on a 6-tonne converter was being built at IMIS along with two 6-tonne direct reduction reactors. Planned to start up pilot plant in October/November 1986, but start-up was delayed to first quarter 1987.
  The total cost of the pilot plant installation, which includes induction melting furnaces, a 6-tonne electric arc furnace, a steel ladle reheating and vacuum degassing unit, in addition to the 6-tonne nominal capacity universal oxygen converter, was US $3 million.
- ZIA Steel Inc, USA, has signed letter of intent with IMIS - provided that IMIS demonstrates the operability of the process at IMIS and their capability of installing several miniplants of 300 000 tonnes/year using exclusively lignite and iron ore as raw material.
- Cuba was about to authorize (in 1987) a project with IMIS to use the wastes of chromium and nickel ores and, as the energy source, the carbon produced using bagasse cane.
- Appear to desire an international joint venture to fully prove the process on a larger scale.

Potential Contacts:

Mr. Arturo Lazcano Navarro

References:

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- "Progress Made in the IMIS Process for Direct Steelmaking", 1990, Steel Times International, January, pp 36 and 38.
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22. K. Koch, U. Härter, and R. Bruckhaus, "Laboratory Studies on Smelting Reduction - A Contribution to Reaction Mechanisms in the Production of Liquid Iron from Iron Oxide Melts", 1989, Steel Research 60, Verlag Stahleisen mbH, no. 3 + 4, pp 171 to 175.

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II. BLAST FURNACE ENHANCEMENTS

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1 SSAB is also an excellent example of "standard" coal injection.

2 Hoogovens, Ijmuiden, is also developing intensified coal injection.

1. COAL INJECTION - SIDMAR

Practitioner:

Sidmar

Purpose:

Decreased dependency on coke; decreased hot metal cost.

Principles:

Essentially standard Paul Wurth coal injection technology. Injection rates are 120 kg coal/thm on Furnace A and 100 kg coal/thm on Furnace B.

Conditions:

- HBT: 1000°C → 1200°C
- blast moisture: 10 g/Nm^3 → natural humidity
- oxygen enrichment: 1% → 2.5%

Status:

Operational - standard practice.

Potential Contacts:

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References:

- A. Hamilius et al, "L'Injection de Charbon Pulvérisé aux Hauts Fourneaux de Sidmar", 1989, La Revue de la Métallurgie - CIT, May, pp 393 to 403 (paper presented at the Journées Sidérurgiques de l'ATS, Paris, November 30 to December 1, 1988).
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Note: SSAB are also an excellent example of "standard" coal injection. SSAB uses Klöckner technology. The maximum injection rate they use at this time is ~95 kg/thm.

2. INTENSIFIED COAL INJECTION - THYSSEN STAHL AG

Developer of Intensified Injection:

Thyssen Stahl AG

Purpose:

Decrease dependence on coke; lower hot metal cost.

Principles:

Küttner coal injection system at Schwelgern, Paul Wurth system at Ruhrort, and cooperative development system at Hamborn. Essentially standard coal injection operation with some O_2 enrichment of the hot blast and maximum (1200°C) HBT (O_2 enrichment to 22.4 % O_2).

Status:

- Trials up to 180 kg pulverized coal/thm.
- Pulverized coal injection is standard practice at Thyssen Stahl AG; standard practice at Schwelgern no. 1 blast furnace is now (end 1989) just over 160 kg/thm, assisted by 1 to 1.5 percent enrichment oxygen.

Potential Contacts:

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M. Peters
K. H. Kreibich

References:

- K. Langner and T. Boeck, "Optimization of Control of Coal Dust Injection into the Blast Furnace", 1989, Metallurgical Plant and Technology 2.
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Note: Hoogovens, Ijmuiden, are also developing intensified coal injection. They, too, have successfully tested injection rates of 170 to 180 kg/thm, but they use slightly higher levels of oxygen enrichment than does Thyssen Stahl.

3. OXY-COAL BLAST FURNACE PROCESS - BSC

Developer:

British Steel Corporation

Purpose:

To use high levels of coal and oxygen in an otherwise conventional blast furnace to maximize the replacement of coke. The process aims to achieve the cost savings projected for coke replacement with coal, and the thermochemical efficiencies of fully counter-current operation, whilst using existing plant and equipment with a minimum of capital investment. The aim is a coal injection rate of 400 kg/thm.

Principles:

Similar heat release and reducing gas generation can be achieved by partial combustion of coal with oxygen as by combustion of coke with preheated air, which allows the process fuel requirement to be provided by coal, whilst retaining the physical and chemical contributions to burden support, heat transfer and reforming of oxidized gases provided by coke.

The application of oxy-coal smelting technology on a blast furnace offers not only greater levels of coke replacement than conventional coal injection, but also a potential increase in productivity and increased top gas calorific value for a relatively low capital cost scheme which can be applied in stages thus minimizing technical risk.

Status:

- Theoretical studies
  Table I and Figures 34 and 35 (all Smith and Corbett, 1985) show the results of theoretical studies.

Table I: Calculated Operating Conditions for Varying Levels of Oxy/Coal Injection in the Blast Furnace

	Dry Coal Injection Rate (kg/thm)	Dry Coke Rate (kg/thm)	Oxygen Injection Rate (kg/thm)	Air Blast Volume (Nm^3/thm)	Heat Content of Topgas (GJ/thm)	Topgas Temp (°C)	Topgas Calorific Value Nett (MJ/Nm^3)
Base Case	0	489.5	0.040	1076	5.122	130	3.185
	88.3	420.7	0.122	875	5.596	127	3.730
	220.7	317.2	0.243	576	6.303	123	4.702
	264.8	282.7	0.276	500	6.545	133	5.009
	353.1	213.4	0.357	298	7.010	130	5.853
	441.4	144.1	0.430	123	7.482	140	6.739
100% Oxygen	485.5	109.2	0.477	0	7.706	125	7.430

Figure 34: Base Case
100% Hot Blast
(No O_2 Enrichment)

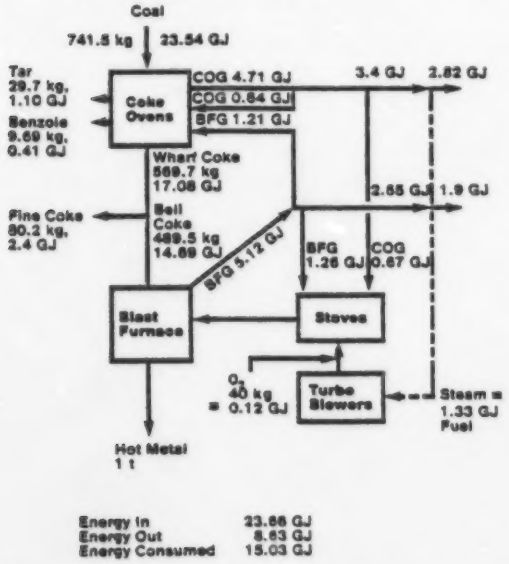
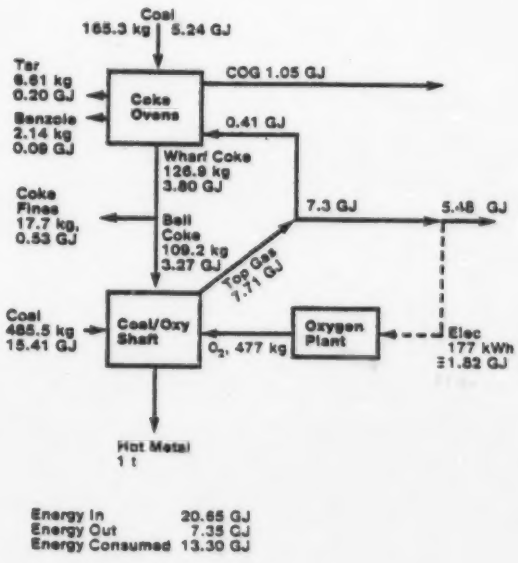


Figure 35: 100% Oxygen



- Laboratory-scale tests have been carried out using an oxy-coal fired melting furnace of approximately 20 kg/hr capacity, charged with DRI and coke.
- An extended trial injecting coal and oxygen through a single tuyere on a production blast furnace (local injection rates ≡ 200 to 300 kg coal/thm).
- (1989) coarse coal injection was first practiced at Scunthorpe Works and now is installed at Ravenscraig Works. Progression to very high rates of injection is projected through the use of oxy-coal lances.

- (1989) British Steel has been joined by Hoogovens and Ilva (formerly Italsider) in a £6.4 million research program that will attempt to inject up to 400 kg coal/thm. This technology is being developed at BSC's Cleveland Works.
- (1990) tests under way at Cleveland Works; program expected to take two years to complete. The coal injection rate will be increased gradually over this time. This test work is being supported by the ECSC Iron and Steel Demonstration Program.

Potential Contacts:

R. B. Smith
M. J. Corbett
Dr. R. Baker - Director of Research and Development BSC

Note:

1. Detailed planning and design of an installation for a multiple tuyere trial in early 1986 was in progress in 1985.

2. Equipment at Teesside Laboratories was to form the basis for pilot plant studies in parallel with full-scale plant trials (1/3 t/h direct reduction and gas reforming plant suitable for conversion to a pilot blast furnace).

   No further word on either.

3. If the test work is successful, it is anticipated that its advanced injection technology will be applied to the Redcar no. 1 blast furnace by the middle of this decade.

References:

- R. B. Smith and M. J. Corbett, "Coal-Based Ironmaking - A Study", 1985, ECSC-Sponsored Research Project, Agreement No. EC1-1274-B7240-84UK, BSC Ref: FR 158-3/852, September.
- G. J. McManus, "Coal Gets a New Shot", 1989, Iron Age, January, pp 31, 32, 36, 38.
- "Developments in British Steel", 1989, Ironmaking and Steelmaking, Vol 16, No. 3, p 146, (News from Industry).

4. EXPERIMENTAL OXY-COAL OPERATION, ANSHAN

Developer:

Anshan Iron and Steel Co

Purpose:

Decreased dependency on coke; lower cost hot metal.

Principles:

Injection of high levels of (pulverized ?) coal into the blast furnace with the aid of oxygen enrichment of the hot blast.

Status:

- Industrial experiment: coal injection of 170 kg/thm with oxygen enriched hot blast to 28.6% O_2.
  - smooth furnace operation,
  - per +1.0% O_2
    - 2 - 3% increase in production
    - 0.5% decrease in coke rate
    - 12 - 13 kg/thm increase in coal injection (+ 1 kg coal/thm = -0.8 kg coke/thm)
    - + 2.6% increase in heating value top gas
    - improved metal quality
    - 1 to 3 yuan (RMB) decrease/tonne hot metal

Potential Contacts:

L. Cheng
G. Gao
S. Ma

References:

- "Experiment of BF Operation with High-Oxygen-Rich-Coal Injection at Anshan Iron and Steel Co", 1988, Iron Steel (China) 23, (11), November, p 1 to 10.

5. OXY-COAL INJECTION PROCESS - NKK

Developer:

Nippon Kokan KK

Purpose:

Improve blast furnace operations; alternatives to new smelting-reduction processes.

Principles:

Inject 250 to 300 kg pulverized coal/thm with oxygen through the tuyeres. Additionally, inject hot top gas in the middle of the blast furnace to preheat and reduce the descending burden materials.

Status:

- Under development.
- Tests on small experimental blast furnace (results included higher productivity, i.e. from 2.2 $t/m^3.d$ to >5 $t/m^3.d$ with greatly lowered coke consumption).

Potential Contacts:

Y. Ohno - Steel Research Centre,
H. Hotta Nippon Kokan, KK
M. Matsuura
M. Mitsufugi
H. Saito

References:

- The Tex Report, 1989, May 12.
- Y. Ohno et al, "Development of the Oxygen Blast Furnace", 1988, Proceedings Process Technology Conference, pp 195 to 201.

6. FLOSS PROCESS

Developer:

Dr. mont Ferdinand Fink, Consultant, Steinbach, FRG

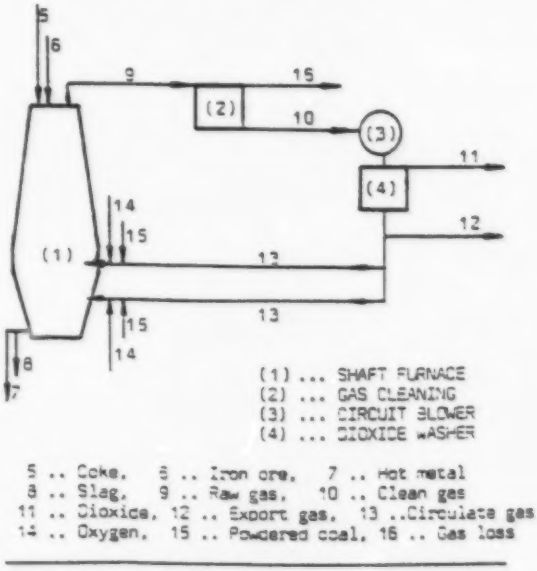
Purpose:

To develop a nitrogen-free blast furnace process.

Principles:

The Floss process is described diagrammatically in Figure 36.

Figure 36: Floss Furnace
(Sketched Flowsheet) (Fink, 1986)



The shaft furnace is designed much like a blast furnace, but equipped with two sets of tuyeres, one at the hearth level and one at the height of the bosh.

All the tuyeres perform like parallel-flow burners. Cold circulating gas, which may be loaded with powdered coal, and cold oxygen get mixed shortly before entering the furnace and this blend ignites immediately.

Gas cleaning is carried out in the same manner as at the blast furnace.

The circuit blower circulates the gas through the carbon dioxide washer, the shaft furnace, and the gas cleaning elements. This circuit may be pressurized and the export gas branched off from it may be expanded for power generation.

The carbon dioxide washer works via approved processes employing well-known solvents. One-step processes, which render roughly cleaned gas by circulating roughly regenerated solvents, perform satisfactorily.

Oxygen is delivered pure (99.5% O_2) by known air separation plants.

The process is stated to operate without "solution loss", and without cohesive layer. By injecting coal through the tuyeres coke rates of less than 200 kg/thm are stated to be achievable. Furthermore, the export gas quantity is stated to be controllable within wide margins, and to produce no cyanides and no NO_x. The process is stated to be capable of smelting pellets or sinter of Ti-bearing ores ("because at smelting, no titanium carbonitrides will originate within the hearth").

Status:

- German patent No. 22 61 766
- No evidence of experimental work

Potential Contacts:

- Dr. mont Ferdinand Fink, Consultant,
  Feldbergstrasse 88
  D-6374 Steinbach
  FRG

Reference:

- Dr. mont Ferdinand Fink, "The Floss Furnace - A New Process to Smelt Iron in Blast Furnaces", 1986, Proceedings European Ironmaking Congress, VDEh, September 14 to 17, Aachen, FRG.

Note: Japanese and Chinese scientists are also working on the development of the nitrogen-free blast furnace.

7. TULA FULL-OXYGEN BLAST FURNACE PROCESS

Developer:

The Tula Ironmaking Plant
The Institute of New Metallurgical Processes, I. P. Bardin Central Research Institute of Iron and Steel Industry

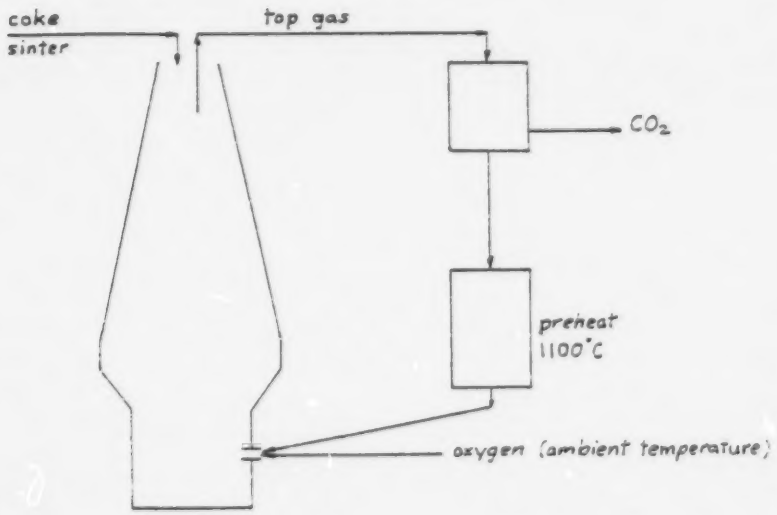
Purpose:

To minimize coke consumption.

Principles:

Figure 37 is a sketch of the Tula oxygen blast furnace process.

Figure 37: The Tula Oxygen Blast Furnace



This 7-metre hearth diameter blast furnace produces foundry iron. (There are no steelmaking facilities at Tula, which is located ~150 km south of Moscow.) It is one of three blast furnaces at Tula.

The furnace is charged with sinter and coke. All the blast furnace gas produced by this furnace, after being stripped of carbon dioxide (CO_2), is preheated to 1100°C in modified stoves and injected back into the blast furnace through the tuyeres (via the hot blast main, bustle pipe, etc). Oxygen is also injected through the tuyeres. No additional fuel is injected.

The productivity increased by about 30 percent upon switching to full-oxygen operation. The coke rate is low. (SSAB estimates that with this process the coke rate on their no. 2 blast furnace at Luleå would drop to 320 to 330 kg/thm.)

This full-oxygen furnace produces no export gas (100 percent recirculation); to preheat the returning CO_2-free top gas, they must use the gas from another blast furnace at the Tula plant operating in the "normal" mode.

The one blast furnace has been operating in the full-oxygen mode for about five years. However, it can operate in this mode only for about one-half of each year. In the winter it is operated as a "normal" blast furnace so that the off-gas may be exported to the local community for fuel.

Future:

- In five years, two more blast furnaces in the USSR are expected to be equipped for full-oxygen operation, another one at Tula, and one in Lipetsk.
- In 10 years, the USSR is expected to have 10 to 12 such furnaces.
- The technology is for sale.

Contacts:

Dr. V. A. Sinelnikov, Director, Institute of New Metallurgical Processes
I. P. Bardin Central Research Institute of Iron and Steel Industry

Reference:

- Private communication with MEFOS and SSAB.

8. TUYERE-ORE-PLASMA (TOP) PROCESS

Developer:

IRSID - CIREP

Purpose:

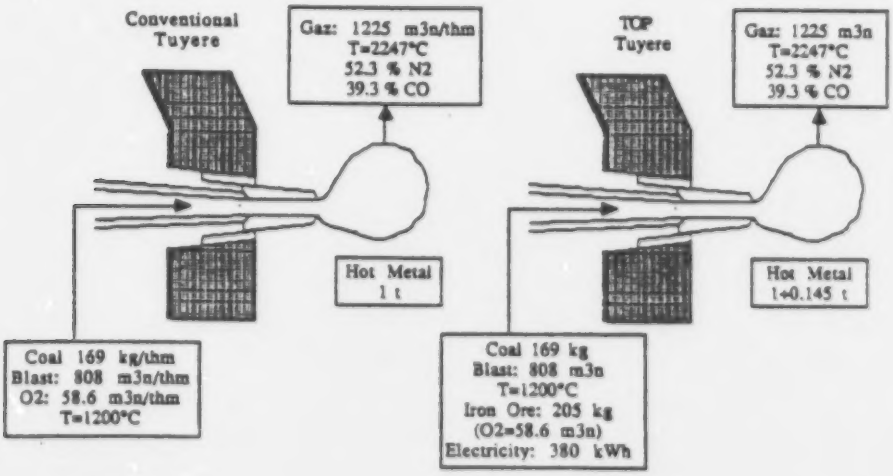
A blast furnace process which uses raw ore (i.e. unagglomerated) and coal directly, thereby minimizing the need for auxiliary plants.

Principles:

The basic idea of the TOP Process is a sensible increase in the production from an existing blast furnace without any enlargement of the auxiliary works (sintering machine and coke ovens) and without any modification of the counter-current operation in the bosh and stack of the furnace.

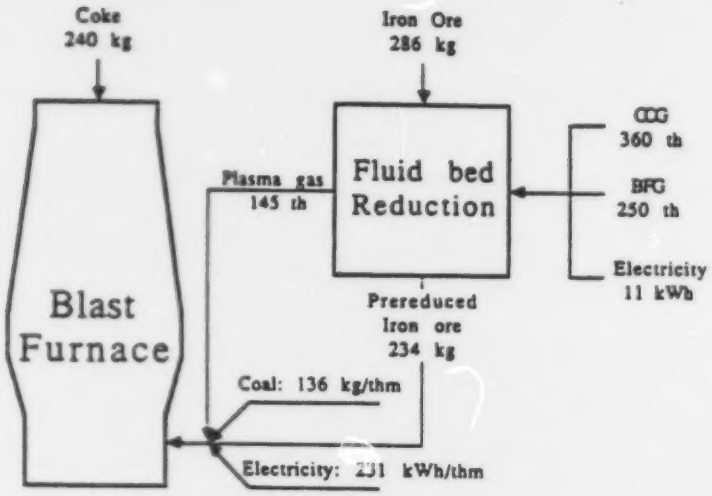
Normally, when high levels of coal injection are practiced, oxygen is required to enrich the hot blast. In the TOP process, the normal gaseous enrichment oxygen is replaced by oxygen tied up as iron oxide. The additional energy required for this type of operation (i.e. iron oxide dissociation, iron and gangue melting and heating to tapping temperature, heating of the released oxygen to blast temperature, etc) may be supplied by plasma (Figure 38).

Figure 38: Principle of the TOP Process (de Lassat de Pressigny and Michard, 1988)



Injecting oxidized iron ore allows a rather large increase in production but means a significant electricity consumption. Partial reduction of the iron ore will decrease the heat input required for the dissociation of the iron oxides, the main energy requirement for the production of extra hot metal. Figure 39 is a possible flow diagram of the TOP process with prereduction of the iron ore.

Figure 39: Prospective Flow Diagram of the TOP Process with Prereduction of Iron Ore (de Lassat de Pressigny and Michard, 1988)



Status:

- Under study.
- Five-day experiment conducted on a blast furnace at Uckange; 180 tonnes of DRI fines (<5 mm) were injected at rates up to 1800 kg/hr together with pulverized coal and plasma. Data are still being analyzed.
- According to an IRSID representative, the TOP process represents the next generation of blast furnace ironmaking; estimated time frame ~2010. [Note: with its dependency on plasma, this process will need an abundance of low-cost electricity which will limit its utilization.]

Potential Contacts:

Yann de Lassat de Pressigny - IRSID - CIREP
Jean-Alex Michard - IRSID - CIREP
Rémy Nicolle - IRSID - CIREP

References:

- Y. de Lassat de Pressigny and Jean-Alex Michard, "The TOP Process, A New Ironmaking Process at the Blast Furnace", 1988, Proceedings Process Technology Conference, AIME/ISS, pp 203 to 208.
- Y. de Lassat de Pressigny and Jean-Alex Michard, "Le Procédé PTM: un Nouveau Procédé d'Elaboration de Fonte au Haut Fourneau", 1989, La Révue de la Métallurgie - CIT, January, pp 37 to 42.
- Y. de Lassat de Pressigny, "Future Directions of Blast Furnace Ironmaking", 1990, International Symposium/Workshop on Future Ironmaking Processes, Steltech, Hamilton, Canada, June 14 and 15, pp 3-1 to 3-13.

9. SACILOR-IRSID-FONTE-FERRAILLES (SIFF) PROCESS

Developer:

Sacilor
IRSID

Purpose:

A process to charge 100 percent scrap to a blast furnace.

Principles:

Charge 100 percent scrap to the blast furnace. Scrap is sized so as to pass through the charging system. Scrap must have good flowability. Charge is mostly steel scrap, but with some selected iron scrap (including 25 percent pig iron). Coke rate: 164 kg/thm.

Status:

- Tested on the no. 3 blast furnace at Sacilor Rombas (12 tuyeres, 6.7 m hearth diameter, inner volume 816 m^3). The coke rate was 164 kg/thm.
- Test was in 1983, work was reported in 1988: no additional effort has been expended in between and no plans for further effort have been announced.
- The technology is for sale.

Potential Contacts:

M. Dietlin - Sacilor
J. Leidwanger
J. Vergnaux

M. Helleisen - IRSID
M. Schneider

References:

- M. Dietlin et al, "A New Way for Producing Pig Iron from Scrap Iron: The SIFF Process Tested in Sacilor Rombas, March 1983", 1988, Journées Sidérurgiques ATS, Paris, November 30 to December 1.

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2. "Pulverized Petroleum Coke for Blast Furnace Injection", 1989, Japan Metal Bulletin, May 11, NKK, (news item).

3. "Raceway Conditions during Coal Injection under Investigation", 1989, McMaster University Symposium on Coke Properties Required for a Stable Blast Furnace Operation, Hamilton, Ontario, Canada, May 30 to June.

4. "Plasma-Electro-Coal Process May be Suitable for Blast Furnaces", 1988, Iron and Steel (China), October.

5. R. R. Willmers, "The Effect of Blast Furnace Coal Injection upon Bosh Coke Properties, Coke Combustion, and Furnace Permeability", 1989, I&SM, August, pp 27 to 35.

6. G. J. McManus, "Coal Gets a New Shot", 1989, January, pp 31 to 38.

7. M. Qin et al, "Blast Furnace Operation with Full Oxygen Blast", 1988, Ironmaking and Steelmaking, Vol 15, No. 6, pp 287 to 292, (paper study).

8. W. P. Hutny and J. T. Price, "Importance of Tar Content in Selecting Coals for Blast Furnace Injection", 1989, Ironmaking and Steelmaking, Vol 16, No. 3, pp 165 to 167.

9. J. Cappel et al, "Stand der Kohleeinblastechnik in den Hochofen bei Mitliedswerken das VDEh", 1988, Stahl und Eisen 108, No. 9, pp 459 to 467, (trans. "Present State of Blast Furnace Coal Injection Technology in Member Works of the VDEh").

10. P. K. Bose, "Oxygen Enrichment Application in the Field of Blast Furnace Productivity and Coke Economy", 1987, Indian J. Cryog, Vol 12, No. 1, pp 32 to 43, (oxygen production method).

11. H. Yamaoka, "A Study on the Oxygen Blast Furnace Through a Mathematical Simulation Model", 1989, CAMP - ISIJ, Vol 2, p 1029, English abstract (full paper in Japanese).

12. M. Matsuura, "Effect of Shaft Gas Injection on Oxygen Blast Furnace Process with Two-Dimensional Mathematical Model", 1989, CAMP - ISIJ, Vol 2, p 1028, English abstract (full paper in Japanese).

13. K. Takeda, "Effect of Coal Properties on Combustibility of Coal Injected Into BF", 1989, CAMP - ISIJ, Vol 2, p 1036, English abstract (full paper in Japanese).

14. H. Matsuoka, "The Application of Pulverized Coal Combustion Technique to Iron and Steelmaking", 1989, CAMP - ISIJ, Vol 2, p 1052, English abstract (full paper in Japanese).

15. "Energy Prices in the European Community", 1989, Technical Update, BSC, Issue No. 1, Summer, p 17.

16. "British Steel Blast Furnace Performances", 1989, Technical Update, BSC, Issue No. 1, Summer, p 39.

17. P. Greis et al, "Metec '89 - Technical Trends in Metallurgical Plant and Technology", 1989, Metallurgical Plant and Technology, April, pp 18 to 30.

18. "Armco's Brazilian Subsidiary Negotiating to Finance the Installation of a $30 million Coal Powder Injection System at Cosipa", 1989, American Metal Market, October 11 and 12.

19. "Coarse Coal Injection for (French) Blast Furnaces", (PACHA Process), 1989, French Technology Society (FTS), August.

20. J. Cappel et al, "Present State of Blast Furnace Coal Injection Technology in the Member Works of the VDEh", 1988, Stahl und Eisen, 9/88, May, p 95, (in German), p 135, (English Summary)

21. K-H Peters et al, "Operation of a Large-Size Blast Furnace with Various Coke Grades at High Coal Injection Rates", 1989, Stahl and Eisen, 22/89, November 10, pp 43 to 50 (in German), p 138, (English Abstract).

22. W. P. Hutny and J. T. Price, "Regression Equation of the Coke Replacement Ratio for Blast Furnace Coal Injection", 1989, I&SM, September, pp 38 to 41.

23. W. P. Hutny and J. T. Price, "Direct Use of Coal in Blast Furnace Technology", CANMET Report 87-6E.

24. Y. Ohno et al, "Development of Oxygen Blast Furnace Process with Preheating Gas Injection into the Upper Shaft", 1989, Tetsu-to-Hagané, No. 8, (translation by Steltech arrangement).

25. B. D. Andrusko, "Coke Properties Required for a Stable Blast Furnace Operation, McMaster University Symposium, Hamilton, Ontario, Canada, May 30 to June 1, 1989", Steltech Report No. 89R124 TM.

26. K. Langner et al, "Optimization of Control of Coal Dust Injection into the Blast Furnace", 1989, Metallurgical Plant and Technology, February, p 32 to 36.

27. "Modernizations and Upgrades Featured in Ironmaking", (Direction Reduction, Pelletizing Plants, Sinter Plant, Coke Ovens, and Blast Furnace "Roundups"), 1989, 33 Metal Producing, May, pp 22 to 32.

28. D. Ma et al, "Heat and Mass Balance of Oxygen Enriched and Nitrogen Free Blast Furnace Operations with Coal Injection", 1988, Ironmaking Conference Proceedings, AIME/ISS, pp 595 to 609.

29. "Klöckner Stahltechnik BF Coal Injection", KST advertising brochure.

30. F. T. Eichinger et al, "Application of the K-BFI Process at Blast furnace No. 2, SSAB, Luleå", KST advertising paper.

31. "Modern Blast Furnace Design", Paul Wurth Cy, Luxembourg, advertising brochure.

32. S. Tada, "Coal Injection in the Blast Furnace - Kobe Steel Ltd", 1990, International Symposium/Workshop on Future Ironmaking Processes, Steltech, Hamilton, Canada, June 14 to 15, pp 5-1 to 5-24.

III. COKING TECHNOLOGY

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4. ANCIT Formed Coke Process 87

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1. CURRENT (WIDER) COKE OVENS

Developer:

Ruhrkohle AG, Essen, FRG

Purpose:

To cut down the number of cokemaking reactors needed for a definite output by a further increase in productivity to such an extent that all problems of contemporary cokemaking technology can be solved within a new cokemaking system concept in a new comprehensive and economic way. The wider coke ovens are the first step.

Principles:

The design principles are essentially the same as for any slot-type coke oven, only these ovens are wider so as to reduce the number of ovens required and the number of pushes a day. The operating principles are essentially those that are common to slot-type coke ovens, but adjusted to allow for the greater width of the coal mass to be coked.

Status:

- Prosper coke plant of Ruhrkohle AG has been modernized with wider ovens.
- Huckingen coke plant of Mannesmannrohren-Werke AG has been modernized with wider ovens.
- Ruhrkohle is planning the construction of a completely new coke plant, Kaiserstuhl III, to replace two old plants.
- Ruhrkohle is working on concepts for future coking systems.

Potential Contacts:

Dr. G. Nashan, Senior Managing Director - Ruhrkohle AG, Essen, FRG

References:

- G. Nashan, "A New Design of Cokemaking Systems", 1987, Iron and Steel Engineer, May, pp 18 to 27.
- G. Nashan, "New Cokemaking Technology", 1988, Steel Technology International 1988, pp 31 to 34.
- D. Breidenbach et al, "Experiences with Large-Volume High-Capacity Coke Ovens Operation Creating the Basis for Planning the New Kaiserstuhl Coking Plant", 1987, 1st International Cokemaking Congress, Essen, FRG, Vol 2, paper F3, 19 pages.
- G. Nashan, "The Production of Blast-Furnace Coke Can be Secured in the Long Term Ecologically Beneficial and Cost-Efficiently - On the Way to a New Coking System", 1987, 1st International Cokemaking Congress, Essen, FRG, Vol 1, paper A2, 51 pages.

2. JUMBO COKING REACTOR

Developers:

Ruhrkohle AG
Bergbauforschung
German coke oven builders

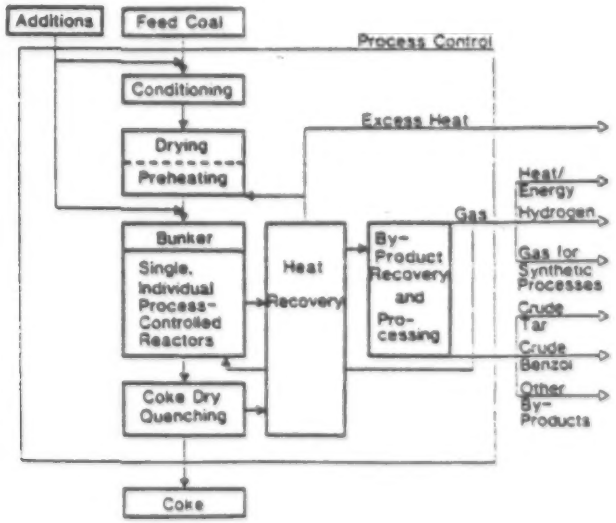
Purpose:

To minimize the number of coking reactors needed for a definite coke production.

Principles:

The basic concept behind the jumbo coking reactor is shown in Figure 40.

Figure 40: Concept of Jumbo Coking Reactor (Nashan, 1987)



The jumbo coking reactor will be so designed that each reactor can be operated as an independent coking unit. Several reactors will be grouped into blocks, but they will not affect one another.

Coke is envisaged to be pushed, "crash-free", by a conventional pusher machine, into a closed cassette presently being developed in the USA by Kress Corporation. Subsequently, the cassette will be transported to the coke dry quench for cooling. The heat of the cooling coke will likely be used to dry and preheat the coal charge.

Emission leakages will be minimized through door design and by minimizing the number and frequencies of openings.

About 33 jumbo coking reactors are estimated to be needed to produce two million tpa coke compared to the 120 ovens of the (latest) Kaiserstuhl III battery.

Status:

- Many calculations completed.
- Small modeling work completed.
- Two half-length jumbo coking reactors are being planned/designed to pilot the process at the Prosper Works of Ruhrkohle; construction is expected to be completed by 1992.
- Project has been approved for the Eureka program, the ECSC's program for the development of technologies required in the future.

Contact:

Dr. G. Nashan, Senior Managing Director, Ruhrkohle AG

References:

- G. Nashan, "A New Design of Cokemaking Systems", 1987, Iron and Steel Engineer, May, pp 18 to 27.
- G. Nashan, "New Cokemaking Technology", 1988, Steel Technology International 1988, pp 31 to 34.
- D. Breidenbach et al, "Experiences with Large-Volume High-Capacity Coke Ovens Operation Creating the Basis for Planning the New Kaiserstuhl Coking Plant", 1987, 1st International Cokemaking Congress, Essen, FRG, Vol 2, paper F3, 19 pages.
- G. Nashan, "The Production of Blast-Furnace Coke Can be Secured in the Long Term Ecologically Beneficial and Cost-Efficiently - On the Way to a New Coking System", 1987, 1st International Cokemaking Congress, Essen, FRG, Vol 1, paper A2, 51 pages.
- G. Nashan, "European Development Centre for Cokemaking Technology - Tasks and Targets", 1990, paper given at a conference in Düsseldorf, FRG, February, 25 pages.

3. FORMED COKE PROCESS, JISF

Developer:

The Japan Iron and Steel Federation
Nippon Steel Corporation

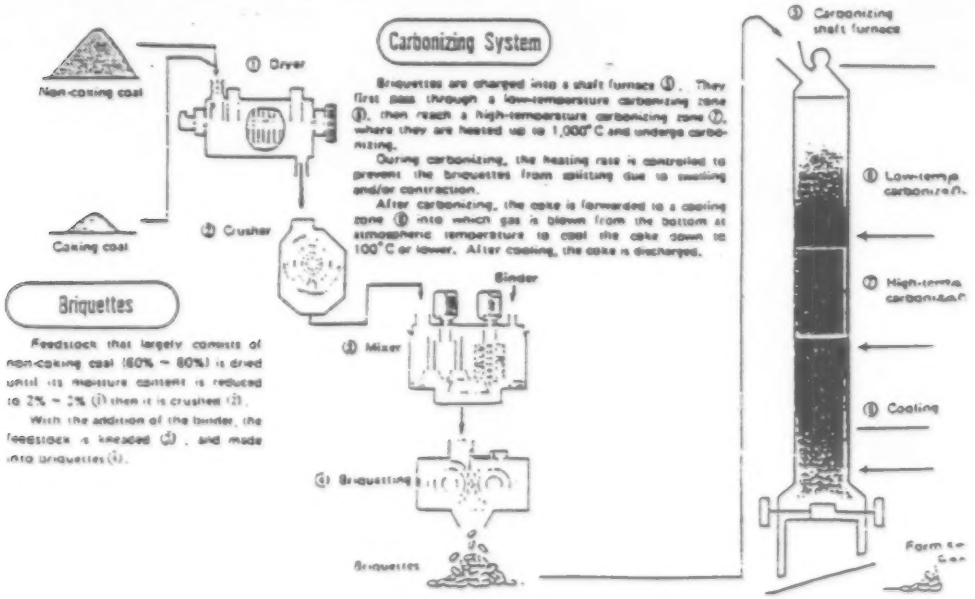
Purpose:

To reduce coke costs by using larger quantities of noncoking coals in the production of metallurgical coke and to reduce air pollution.

Principles:

Figure 41 shows the solids flow in the JISF formed coke process.

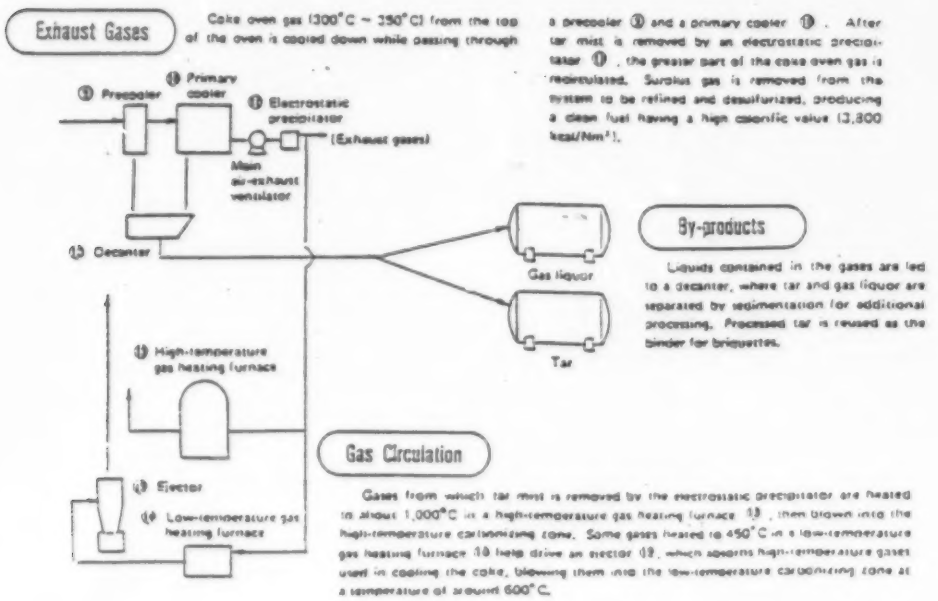
Figure 41: Flow of Formed Coke Process (JISF)



- Feedstock that consists largely of noncoking coal (60 to 80 percent)* is dried to about 2 to 3 percent moisture and then crushed.
- Binder (processed tar from the formed coke process) is added to the crushed coal and then this mix is kneaded and briquetted.
- The briquettes are charged into a shaft furnace in which they first pass through a low-temperature carbonizing zone before reaching the high-temperature carbonizing zone where they are heated up to 1000°C and are completely carbonized. During carbonizing, the heating rate is controlled to prevent the briquettes from splitting due to swelling and/or contraction.
- After being carbonized, the coke passes into the cooling zone into which gas is blown from the bottom at ambient temperature to cool the coke to 100°C or lower. The cooled coke is then discharged.

Figure 42 shows the flow of gases in the JISF formed coke process.

Figure 42: Flow of Gases (JISF)


Exhaust Gases
Coke oven gas (300°C ~ 350°C) from the top of the oven is cooled down while passing through a precooler ③ and a primary cooler ⑨ . After tar mist is removed by an electrostatic precipitator ⑪ , the greater part of the coke oven gas is recirculated. Surplus gas is removed from the system to be refined and desulfurized, producing a clean fuel having a high calorific value 13,800 kcal/Nm³).
⑨ Primary cooler
③ Precooler
⑪ Electrostatic precipitator
(Exhaust gases)
Main air-exhaust ventilator
⑮ Decanter
Gas liquor
Tar
By-products
Liquids contained in the gases are led to a decanter, where tar and gas liquor are separated by sedimentation for additional processing. Processed tar is reused as the binder for briquettes.
⑰ High-temperature gas heating furnace
⑭ Ejector
⑱ Low-temperature gas heating furnace
Gas Circulation
Gases from which tar mist is removed by the electrostatic precipitator are heated to about 1,000°C in a high-temperature gas heating furnace ⑰ , then blown into the high-temperature carbonizing zone. Some gases heated to 450°C in a low-temperature gas heating furnace ⑱ help drive an ejector ⑭ , which absorbs high-temperature gases used in cooling the coke, blowing them into the low-temperature carbonizing zone at a temperature of around 600°C.

- Coke oven gas (300° to 350°) from the top of the oven is cooled down while passing through a precooler and a primary cooler. After tar mist is removed by an electrostatic precipitator, the greater part of the coke oven gas is recirculated. Surplus gas is removed from the system to be refined and desulfurized, producing a clean fuel having a high calorific value (3800 kcal/Nm^3).
- Liquids contained in the gases are led to a decanter, where tar and gas liquor are separated by sedimentation for additional processing. Processed tar is used as the binder for briquettes.
- Gases from which tar mist is removed by the electrostatic precipitator are heated to about 1000°C in a high-temperature gas heating furnace, then blown into the high-temperature carbonizing zone. Some gases, heated to 450°C in a low-temperature gas heating furnace, help drive an ejector which absorbs high-temperature gases used in cooling the coke, blowing them into the low-temperature carbonizing zone at a temperature of around 600°C.

---

* 100 percent has been tested successfully.

Status:

- The project was carried out by four steelmakers under the auspices of the Committee for Research and Development on the Formed Coke Process, which was created by the Japan Iron and Steel Federation in 1978. The four companies are Kawasaki Steel, Kobe Steel, Nippon Steel, and Nippon Kokan.
- The 200-tonnes/day pilot plant, constructed at the Yawata Works of Nippon Steel Corporation, produced 93 000 tonnes of formed coke during 580 days of operation between June 1984 and December 1986. The shaft furnace of the plant is 6.45 m long x 1.25 m wide x 14 m high (In a test run, productivity reached 300 tonnes/day).
- Tobata No. 4 Blast Furnace was continuously charged with 20 percent formed coke for 74 days from October 22, 1986, to January 3, 1987. This furnace has an inner volume of 4250 m^3 and a capacity of 8000 tonnes/day. Up to 30 percent formed coke was successfully demonstrated during this test run.
- Calculations based on the pilot plant test results and a 3000 tonnes/day formed coke plant versus a 3000 tonnes/day conventional coke plant indicated that the formed coke manufacturing process is fully competitive with the conventional coke manufacturing process.

References:

- "The Formed-Coke Process", The Japan Iron and Steel Federation (JISF) paper.
- "Development of Formed Coke Process", 1988, Nippon Steel Corporation, May, paper.
- McMaster University Symposium on Coke Properties Required for a Stable Blast Furnace Operation, May 30 to June 1, 1989.

4. ANCIT FORMED COKE PROCESS

Developer:

Eschweiler Bergwerks-Verein (EBV) AG
Dutch State Mines (DSM)

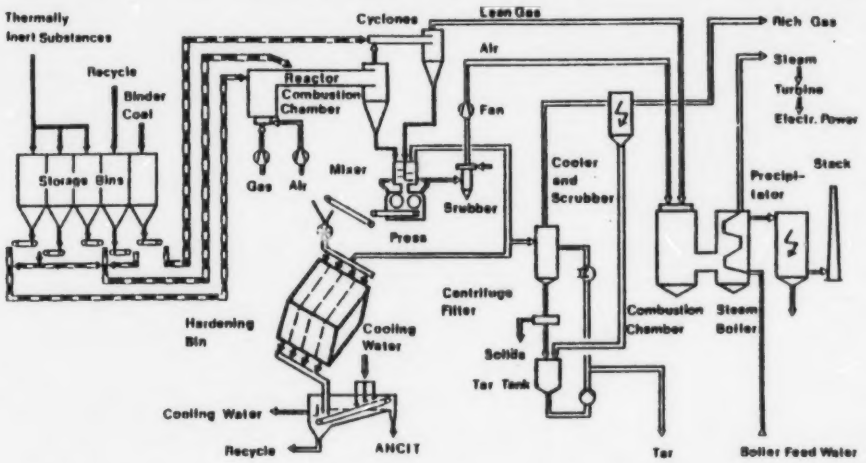
Purpose:

To develop a continuous cokemaking process which is less costly than conventional coke ovens requires less energy/unit of output, and has a low pollution level.

Principles:

Figure 43 is the flowsheet of the ANCIT formed coke process.

Figure 43: Flowsheet, ANCIT Formed Coke Process (Beckman and Wagner, 1987)



The ANCIT process is a five-stage process. In stage 1, the solids are metered into three streams for conveying to the flash reactors. Stage 2 comprises particle disintegration by heat shock and provides all the heat necessary for the process. Stage 3 includes the blending and kneading of the hot solids. Stage 4 is the briquetting of the hot, crumbly, briquetting blend (pressure 10 kN/cm, i.e. 500 kN for the 56 cm wide press at Alsdorf) into low-temperature coke briquettes. Briquette volume can be varied between 15 and 500 cm^3 each. The fifth stage is curing in the post-hardening bin.

These briquettes are sold on the European market as smokeless fuel.

The optimum briquette size as a blast furnace charge component is stated to be 70 to 90 cm^3, for cupola melting furnaces, about 500 cm^3.

Alsdorf ANCIT formed coke was used in the 1970s for the production of pig iron in a series of trials in German, Belgian, and Luxembourgian blast furnaces. In three operating periods of several weeks,

up to 50 percent ANCIT formed coke was used with 50 percent lump coke. Up to 30 percent ANCIT formed coke, the blast furnace had the same efficiency as with 100 percent lump coke. The ANCIT formed coke was produced from a blend of two-thirds low volatile coal and one-third coking coal.

Status:

- Commercial, but small; in continuous operation since 1967 and in that time has produced more than 1.5 million tonnes of formed coke.
- Laborlux SA has taken over the Alsdorf plant since the beginning of the 1980s and are expanding their operations. (Laborlux is a joint stock company under Luxembourg law. The majority shareholder is ARBED SA; one-quarter of the capital is owned by the Grand Duchy.)
- Not likely to be a contender for a coke substitute.

References:

- F. H. Beckmann and H. Wagner, "ANCIT - Formed Coke and Formed Blend Cokes by Hot Briquetting", 1987, 1st International Cokemaking Congress, Essen, FRG, September 13 to 18, Vol 2, paper F6, 20 pages.

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2. "Twenty-two Percent of Japan's Coke Ovens are Over Twenty Years Old", 1989, I&SM, August, p6. (Coke supplies will be insufficient for Japan's need by 2005, if no new batteries are built.)

3. P. E. Champagne and J. A. Lewis, " The Coke Dilemma", 1989, I&SM, August, pp 21 to 26. (The critical period for major domestic (US) coke production deficits appears to be from 1996 to 2000, rather than from 1989 to 1995.)

4. "Coal Association has Bullish Outlook in Forecast for Remainder of Century", 1989, Energy Report, March 6. (US coal production will increase 20.6 percent from 1987 to 2000 according to the (US) National Coal Association.)

5. Nachrichten fur Aussenhaudel, 1989, March 7, p 8 (in German). Description of world coal production in 1988.)

6. G. J. McManus, "Steel Fires up Renewed Interest in Coke", 1989, Iron Age, January, pp 21 to 29. (State of interest in coking capacity among US steel producers. Also describes NIPSCO's interest in operating a merchant coke plant for coke sales to steel industry and utilization of byproducts to generate electricity thermally.)

7. "Surplus Coking Capacity Seen in US into 1990s", 1985, American Metal Market, October 16.

8. "Bethlehem, USX Order BHP Coke", 1987, American Metal Market, July 22. (Over 10 000 tonnes in trial shipments for Bethlehem's Sparrows Point plant and USS' Fairless Works.)

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20. K. P. Svoboda, "A Second Look at Cogeneration in a Coke Oven Plant", 1990, Iron and Steel Engineer, February, pp 27 to 31.

21. T. G. Callcott and R. Callcott, "Coking with Australian Coals", 1990, Cokemaking International, Association of German Cokemaking Experts (VDKF), Vol 1, No. 1, pp 22 to 28.

22. T. G. Callcott et al, "Coals in Future Iron and Steel Making", 1990, Conference on Imperatives for Coals and Metallurgy, Australian Institute of Energy, Newcastle Group, Newcastle, Australia, May 23, 7 pages.

23. M. Khan, "The Future of Cokemaking", 1990, International Symposium/Workshop on Future Ironmaking Processes, Steltech, Hamilton, Ontario, Canada, June 14 and 15, pp 8-1 to 8-23.

IV. COAL IN STEELMAKING

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A 1. ARBED LANCED COAL INJECTION (ALCI) PROCESS

Developer:

ARBED
Nippon Steel Corporation

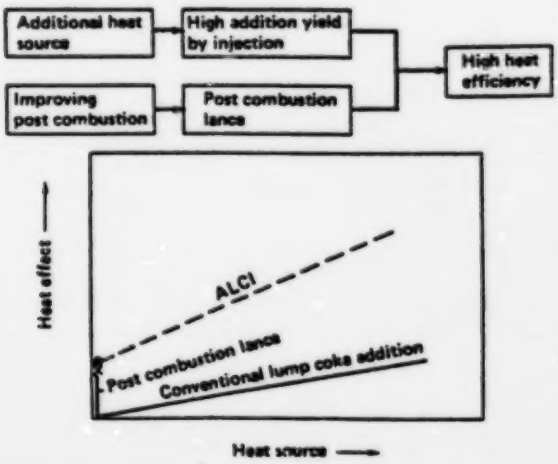
Purpose:

To increase the scrap-melting capacity of the BOF.

Principles:

The basic idea behind the ALCI process is shown in Figure 44.

Figure 44: Basic Idea of ALCI (Klein et al, 1985)



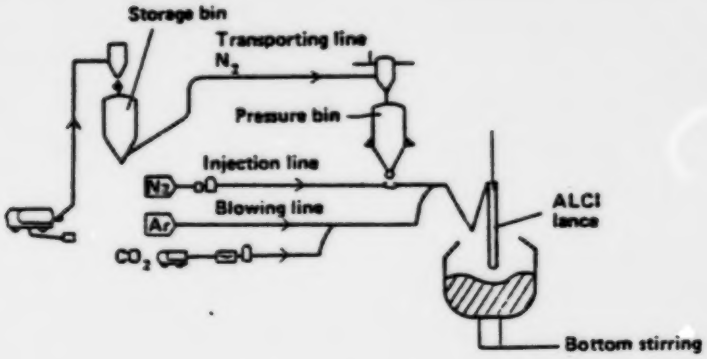
The basic idea of ALCI is to increase BOF scrap-melting capacity by adding fine coal as an additional heat source together with improving post combustion of CO in the vessel.

The characteristics of ALCI include:

- simultaneous coal injection and post combustion.
- coal is an inexpensive heat source and can be utilized with quite high thermal yield by injecting it in the proper size distribution.
- the conventional BOF can be converted to ALCI processing within a vessel refractory reline period.

Figure 45 shows the ALCI process as it is installed at NSC's Kimitsu Works.

Figure 45: Total System of ALCI in Kimitsu (Klein et al, 1985)



The process evolves around the special ALCI lance (built and supplied by Paul Wurth Co.) which injects both coal and oxygen from the top. It is essentially a normal oxygen lance modified to allow the injection of coal down its middle. Normal lance tip life, with or without coal injection, is 100 to 200 heats. Bottom stirring is practiced simultaneously (combined blowing).

ARBED injects, on average, about three tonnes of coal a heat, which adds about 10 min to the heat time, i.e. from about 40 min to about 50 min. One kilogram of carbon melts seven kilograms of scrap.

ARBED processes a high phosphorous pig iron using a double slag practice. The initial slag contains about 18 percent P_2O_5 and is sold for the production of fertilizer. On the other hand, Kimitsu Works, NSC, processes a low phosphorous hot metal which has been desulfurized and desiliconized. Because of the desiliconization, they have about zero capacity to melt scrap, and so they have adopted the ALCI process to be able to recirculate their home scrap. Sulfur pickup is not much problem because they inject Chinese coal containing only about 0.1 percent sulfur.

Paul Wurth has developed a process for lance exchange, even during the processing of a heat, which takes only about five minutes.

Some wear occurs in the piping which transports the coal, but the severity depends on the type of coal being injected. They have used coals containing up to 15 percent volatile matter.

Status:

- In operation at Belval Works of ARBED (high phosphorous hot metal)
- Successfully tested in Nippon Steel Corporation's Kimitsu Works No. 1 BOF Shop and a 250 t LBE vessel (collaborative effort ARBED/NSC). "Additional effort will be made to explore the further possibility of ALCI".
- Commercial - may be licensed.

Licensing Arrangements

- The process may be licensed but, at the moment, no other users exist and marketing efforts are virtually non-existent.
- Any licensing arrangements would be made through the Paul Wurth/ARBED Group, and the actual arrangement would be developed through discussions on an individual basis.
- For coal injection, the licence fee would be "relatively low compared to the cost of the equipment".

Potential Contacts:

H. Klein, Division d'Esch-Belval - ARBED
J. F. Liesch, Division d'Esch-Belval - ARBED
H. Iso, Steelmaking Division, Kimitsu Works - NSC
K. Nakamura, Steelmaking Division, Kimitsu Works - NSC

Actual Contacts:

F. Schleimer, ARBED
R. Henrion, ARBED
G. Bernard, Paul Wurth

References:

- H. Klein et al, "Scrap Ratio Increase by Coal Injection in the BOF", 1985, Proceedings 68th Steelmaking Conference, AIME/ISS, Detroit, pp 129 to 136.
- J. Goedert et al, "The ALCI Process", ARBED information paper.

A 2. BATH AGITATION PROCESS (BAP)

Developer:

British Steel Corporation (BSC)

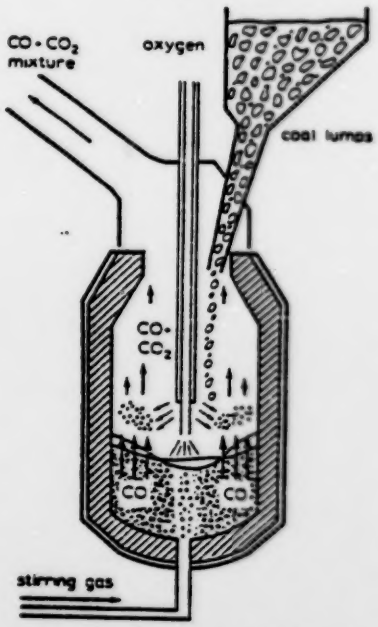
Purpose:

To improve charge flexibility in the BOF process, i.e. increase the scrap: hot metal ratio.

Principles:

A procedure has been developed for adding additional fuel in the form of coal or coke during the blow, and increasing the generation of heat in the vessel using post-combustion nozzles. The general arrangement is shown in Figure 46.

Figure 46: Use of Secondary Oxygen and Coal Additions in Conjunction with BAP



(Ironmaking and Steelmaking, 1989)

Status:

BSC has apparently adopted BAP technology on 11 BOFs, 3 x 242 t at Teesside, 3 x 189 t at Llanwern, 2 x 330 t at Port Talbot, and 3 x 124 t at Ravenscraig (Table II).

Table II: Steelmaking Facilities in British Steel (Ironmaking and Steelmaking, 1989)

Works	Hot Metal Desulfurization	Vessel Size and Type	BOS Process Control	Slag Carryover Control	Stirring and Injection	Vacuum Degassing	Ladle Heating
Scunthorpe	Soda ash Mg granules (ladle)	3 x 297 t unstirred	Sublance (1990)	Darts EM coils	3 BOS stir 2 CC stir powder, lead	RH	Ladle furnace (1988)
Teesside	CaC_2 (torpedo) Mg-CaO (transfer ladle injection trials)	3 x 242 t BAP	Sublance (1990)	Slag ball dropper	3 BOS stir powder Al strip Ca, CaSi wire	RH	Ladle furnace (1988)
Llanwern	Magnesium (ladle), (occasional)	3 x 189 t BAP	Sublance (1990)	None	CC stir Al wire	RH	CAS-OB (1989)
Port Talbot	None	2 x 330 t BAP	Sublance (1990)	Darts EM coils	CC stir Al wire	DH	CAS-OB (1989)
Ravenscraig	CaC_2 (ladle)	3 x 124 t BAP	Bomb thermocouple Automatic blowing	Voest plug EM coils	3 CC stir Al strip Al wire Powder	DH	VAD

Potential Contacts:

Dr. Brian Smith
Mr. John O'Hanlon

References:

- "News from Industry", Ironmaking and Steelmaking, 1989, Vol 16, No. 3, pp 146 to 147.
- A. S. Normanton et al, "Incorporation of BAP Technology with Steelmaking at Ravenscraig", 1987, Ironmaking and Steelmaking, Vol 14, No. 5, pp 221 to 229.
- "British Steel-Hoogovens - Bath Agitation Process (BAP) at TATA Iron and Steel, Jamshedpur, India", Technical Update, BSC, Issue No. 1, p 40.

A 3. C-FFOX PROCESS

Developer:

CIREP
Sollac

Preheating scrap to 1100°C in a converter by using coal and oxygen, as developed by CIREP and Sollac, is called the PRE-FER process. Burning part of the iron charge as a fuel with oxygen to melt the scrap and bring the temperature to 1650°C is called the FFOX process. Together, they make up the C-FFOX process.

Purpose:

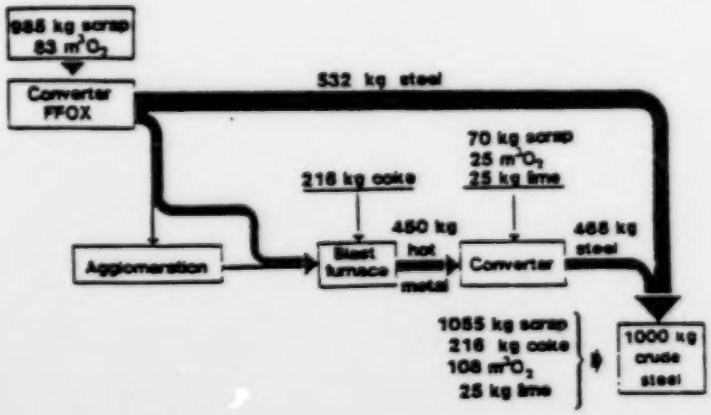
To increase steel output when hot metal is in short supply.

Principles:

- In the PRE-FER process, a load of scrap is first heated to 1000°C in 7 to 10 minutes using 25 to 30 kg anthracite per tonne of scrap.
- Hot metal or additional scrap is added, followed by the FFOX process.
- In the FFOX process the scrap is intentionally oxidized to FeO and Fe_2O_3 to produce heat. The total iron in the slag as oxides is nearly 60 percent (compared to 22 to 25 percent in conventional BOF steelmaking). This high iron oxide slag is recycled by charging it into the blast furnace.

Figure 47 shows the mass balance to produce one tonne of steel by the C-FFOX Process.

Figure 47: Mass Balance to Produce One Tonne of Steel (Kleger and Schaffar, 1986)



The best refractory for the high iron/oxygen content slags is pure magnesia.

Scrap-melting rate is extremely fast; a 70-metric-tonne scrap charge is melted in six to seven minutes.

The steel produced is low in C, Mn, S and Cr.

Status:

- By early 1986, eight industrial heats had been made with the C-FFOX process in a 240-tonne LWS converter and a 250-tonne LBE converter.
- To quote R. J. Fruehan: "It is doubtful that the C-FFOX process will gain wide acceptance in the near future. The iron oxide-rich slag will reduce lining life, the tap-to-tap time for the process is high (reduced productivity), and large quantities of slag must be recycled to the blast furnace. However, it does offer an alternative to the integrated plant when hot metal is in short supply and scrap costs are low".
- From IRSID (1989): "This process works successfully, but the direction in which the industry is going to produce more energy [release] in the steelmaking vessel is post-combustion rather than the burning of steel scrap".
- "Successful", but not likely to see commercial utilization.

Potential Contacts:

Mr. Rémy Nicolle
Mr. Yann de Lassat de Pressigny

References:

- R. Kieger and B. Schaffar, "C-FFOX: Steelmaking by Preheating and Oxidizing Melting of Scrap", 1986, Fifth International Iron and Steel Congress, AIME/ISS, Washington, DC, April 6 to 9, Process Technology Conference Proceedings, pp 1079 to 1082.
- R. J. Fruehan, "Alternate Scrap Melting Technologies, Part II", 1987, I&SM, April, pp 9 to 12.

A 4. KLÖCKNER, VOEST-ALPINE (KVA) PROCESS)

Developer:

Klöckner Stahl, Duisburg, FDR
Voest-Alpine, Linz, Austria

Purpose:

To produce steel in a BOF converter from a 100 percent scrap charge.

Principles:

Process operates on a 100 percent scrap charge "based on know-how acquired by Klöckner in the 1970s" (presumably based on coal/oxygen injection).

Status:

- By August 1987, a BOF converter at Voest-Alpine's Donawitz steelworks was to be re-equipped to operate according to the new process.* Engineering work was to be the responsibility of Voest-Alpine's industrial plant-building company.** Klöckner's steel technology company (KCT) in Hamburg was to supply the gas-feeder equipment together with burners and jets.

  (At the time of the notice in Steel Times, commercial and technical details of the arrangement between Klöckner and Voest-Alpine were yet to be negotiated between Voest-Alpine and the Klöckner-CRA-Technology Group).

- At the time of our visit to KCT, November 17, 1989, the KVA process at Donawitz had been shut down for dioxin emissions.

Potential Contact:

Dr. A. Hauck (since resigned)
Dr. R. M. Flesch
Dr. W. Schlebusch

---

* cost 145 million Austrian schillings ($11.2 million US).

** Voest Industrienlagenbau.

References:

- Steel Times, April 1987.
- American Metal Market, March 23, 1987.
- "Variations on a Theme by Klöckner", 1989, Steel Times International, September, pp 39 to 41.
- L. von Bogdandy et al, "Developments in Oxygen Converter Steelmaking", 1988, Steel Technology International, pp 103 to 108.
- R. M. Flesch et al, "The KCT Process Family: Clean and Economic Steel Manufacturing", 1990, International Symposium/Workshop on Future Ironmaking Processes, Steltech, Hamilton, Ontario, Canada, June 14 and 15, pp 2-1 to 2-23.

A 5. KMS PROCESS (Klöckner-Maxhütte-Steelmaking)

Developer:

Klöckner Stahlforschung, FRG

Purpose:

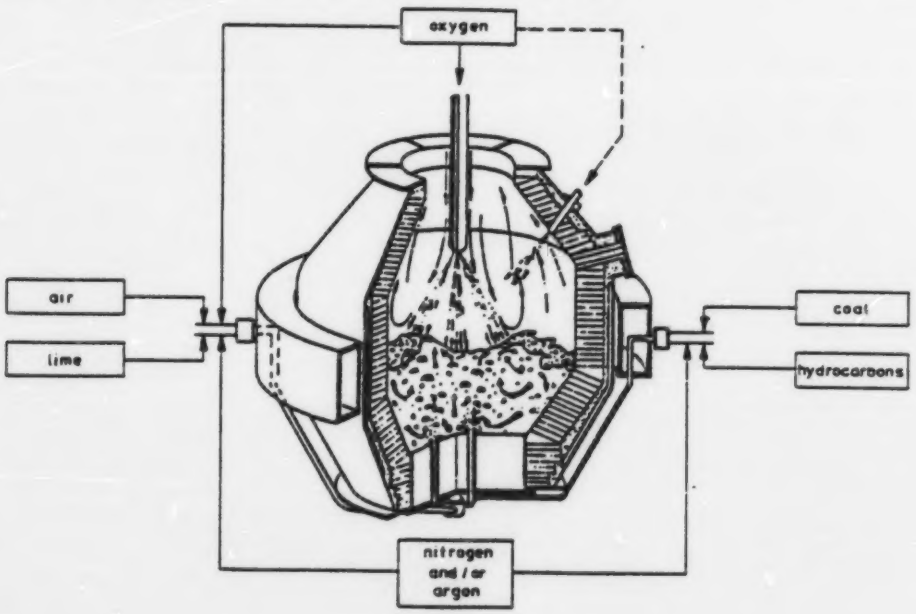
To increase the flexibility of using hot metal and scrap in (BOF-type) steelmaking.

Principles:

- Increased utilization of the off-gases by post-combustion using top and side-blown tuyeres.
- Additional energy input to the vessel by bottom injection of fine coke or coal. (The bottom tuyeres can also be operated as burners with stoichiometric combustion for scrap preheating).

Figure 48 is a diagram of a KMS vessel operation.

Figure 48: KMS, "Klockner-Maxhütte-Steelmaking" (KCT)



Status:

- Three 60-tonne OBM converters of Maximilianshütte have been operating with the KMS practice since 1978.
- KMS offers wide flexibility in terms of accepting a scrap feed between 30 and 65 percent.
- Recent work with scrap preheating has led to a 25 percent cut in net energy input into the KMS vessel at Georgsmarienhütte

- (KS) further flexibility is gained by steelmaking with 100 percent scrap and reinjection of dust. Over 4000 tonnes of dust has been injected (over 70 percent of the dust produced). One tonne of dust requires around 600 kg coal for reduction and conversion to liquid steel.

Potential Contacts:

Dr-Ing. P. Patel - Klöckner-Stahl GmbH, Onasbruck Works
Dr-Ing. H-J Selenz - Klöckner-Stahl GmbH, Onasbruck Works
Dr-Ing. I. Grossmann - Klöckner CRA Technologie GmbH, Hamburg

Actual Contacts:

Dr. R. M. Flesch
Dr. A. Hauck (since resigned)
Dr. W. Schlebusch

References:

- "KMS, K-OBM Steelmaking", KCT advertising brochure/paper.
- E. Aukrust et al, "Steelmaking Technology for the 21st Century. State-of-the-Art Review", 1984, AISI Task Force Report, August.
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- H. G. Geck et al, "Economical and Technical Aspects of Producing High Quality Steel by Allothermic Converters", 1987, Steelmaking Conference Proceedings, AIME/ISS, Pittsburgh, PA, Vol 70, pp 357 to 363.
- K. Brotzmann, "New Concepts and Methods for Iron and Steel Production", 1987, Steelmaking Conference Proceedings, AIME/ISS, Pittsburgh, PA, Vol 70, pp 3 to 12.
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- "Klöckner Technologie Converter Processes", KCT advertising brochure.
- L. von Bogdandy et al, "Oxygen Converter Steelmaking with High Scrap Rates", 1986, Process Technology Conference Proceedings, Fifth International Iron and Steel Congress, AIME/ISS, Washington, DC, April 6 to 9, pp 1083 to 1094.
- R. M. Flesch et al, "The KCT Process Family: Clean and Economic Steel Manufacturing", 1990, International Symposium/Workshop on Future Ironmaking Processes, Steltech, Hamilton, Ontario, Canada, June 14 and 15, pp 2-1 to 2-23.

A 5(a). KS PROCESS (Klöckner Steelmaking Process)

Developer:

Klöckner Stahlforschung, FRG

Purpose:

To produce steel in a BOF converter using a 100 percent scrap charge (one extreme of the KMS Process).

Principles:

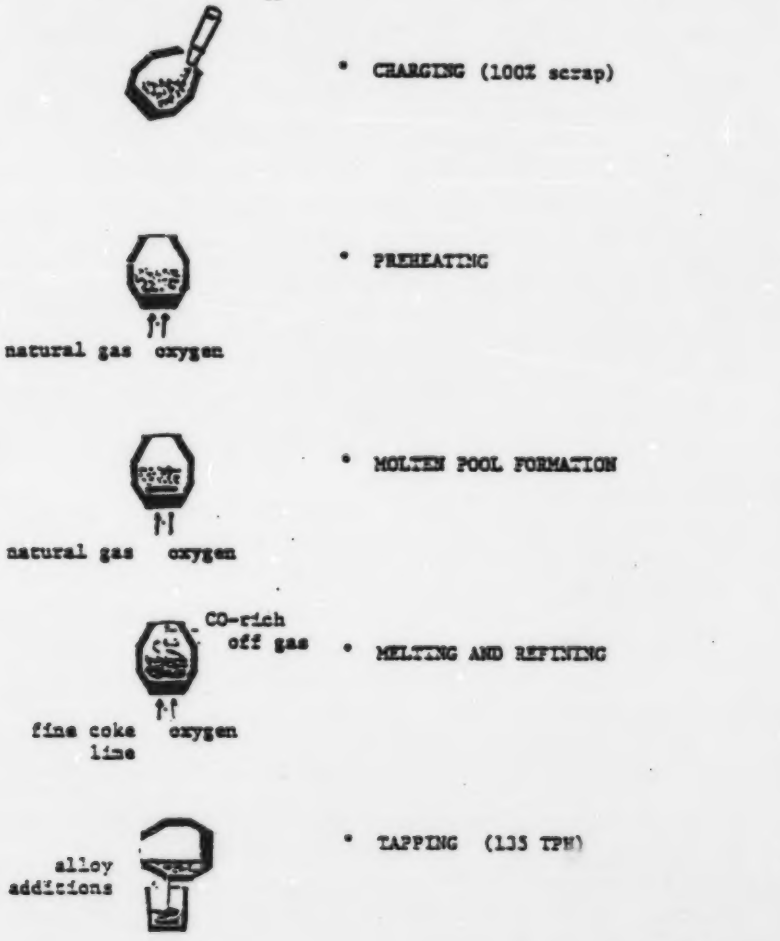
Coal and oxygen are injected into the liquid metal via basal tuyeres to produce heat for scrap melting. Injection of additional oxygen above the bath enables the combustion of the carbon monoxide and hydrogen formed in the bath (post combustion) and, hence, provides additional heat for scrap melting. Typically 20 percent of the CO is burned in this way. Figure 49 shows the various process steps.

The initial melt may be produced from scrap by combustion of natural gas with oxygen through bottom tuyeres; for subsequent heats, a hot heel would be left in the vessel from each tap.

Status:

- The K(M)S process was first developed in the Maximilianshütte plant at Sulzbach Rosenberg. It was introduced in November 1981 at the Georgsmarienhütte (GMH) Works of Klöckner-Stahl GmbH. Over 2.5 million tonnes of steel have been produced and about 360 000 tonnes of coal have been injected since then.
- The KS process was thoroughly tested commercially but, at the time of writing this report, no commercial plant was operating this process nor had any announced plans to do so.

Figure 49: KS "Klockner Steelmaking" (Klockner-Werke AG) 125 ton Melter (One Million TPY) Operating Since May 1983* at Georgsmarienhütte Works, Osnabruck (AISI, 1984)



* no longer in operation as KS

Potential Contacts:

K. Schafer - Klöckner-Stahl GmbH
H. G. Geck
G. Pretzer
H. J. Selenz
P. Patel

Actual Contacts:

R. M. Flesch
A. Hauck (since resigned)
W. Schlebusch

References:

- E. Aukrust et al, "Steelmaking Technology for the 21st Century. State-of-the-Art Review", 1984, AISI Task Force Report, August.
- R. B. Smith and M. J. Corbett, "Coal-Based Ironmaking - A Study", 1985, ECSC-Sponsored Research Project Agreement No. EC1-1274-B7240-84UK, BSC Ref: FR 158-3/852, September.
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- L. von Bogdandy et al, "Oxygen Converter Steelmaking with High Scrap Rates", 1986, Process Technology Conference Proceedings, Fifth International Iron and Steel Congress, AIME/ISS, Washington DC, April 6 to 9, pp 1083 to 1094.
- H. G. Geck et al, "Economical and Technical Aspects of Producing High Quality Steel by Allothermic Converters", 1987, Steelmaking Conference Proceedings, AIME/ISS, Pittsburgh, PA, Vol 70.
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- K. W. Heyer, "KMS/KS Process (OBM Conference, Germany)",1985, Stelco trip report 85R109.
- K. Brotzmann and E. Fritz, "A Step Towards More Economic Steelmaking", 1988, Steel Technology International, pp 136 to 141.
- L. von Bogdandy, "Developments in Oxygen Converter Steelmaking", 1988, Steel Technology International, pp 103 to 108.
- W. Schlebusch and A. Hauck, "Variations on a Theme by Klöckner", 1989, Steel Times International, September, pp 39 to 41.
- "Klöckner Technologie Converter Processes", KCT advertising brochure.
- "KMS, K-OBM Steelmaking", KCT advertising brochure/paper.
- R. M. Flesch et al, "The KCT Process Family: Clean and Economic Steel Manufacturing", 1990, International Symposium/Workshop on Future Ironmaking Processes, Steltech, Hamilton, Ontario, Canada, June 14 and 15, pp 2-1 to 2-23.

A 6. NEW MELTING PROCESS

Developer:

Nippon Steel Corporation

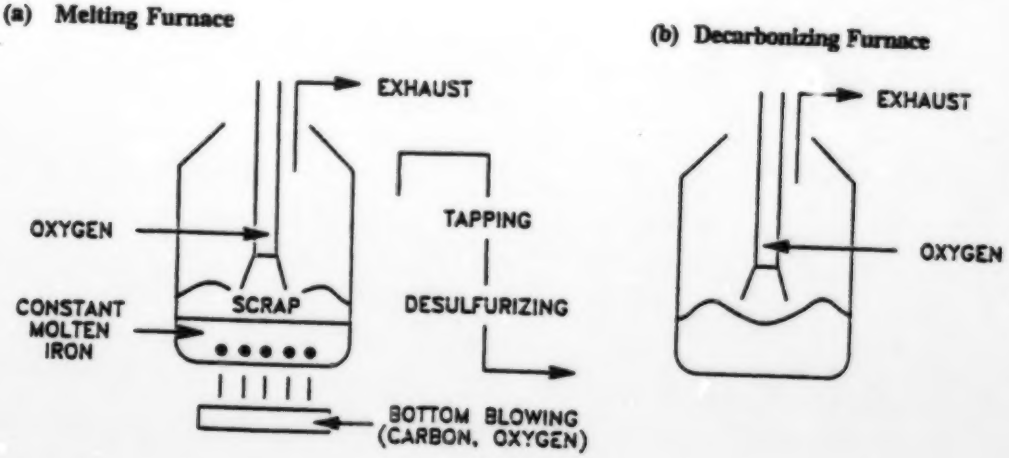
Purpose:

To permit the shutting down of blast furnaces while maintaining steel production at the same level.

Principles:

The principles of NSC's New Melting process are shown in Figure 50.

Figure 50: New Melting Process, NSC (JMB, 1988)



Nippon Steel are converting two BOF shops to their New Melting process - one at Hirohata Works and one at Muroran Works. In each shop:

- 1 BOF → melting furnace,
- 1 BOF → decarbonizing furnace,
- 1 BOF → combination furnace (swing furnace).

The melting furnace will operate as follows. The scrap and pig iron will be charged into the melting furnace on top of a hot heel; coal and oxygen will be blown into the charge from the bottom and oxygen will be blown in from the top. The scrap is to be supplied from Kimitsu and Oita Works.

The decarbonizing furnace presumably operates essentially as a BOF.

The "swing" furnace allows for either of the other two furnaces to be taken down for reline.

Status:

- Postponed through 1989.
- NSC still plans to proceed to adopt this process at Hirohata Works and Muroran Works; now scheduled for March 1991.

Potential Contacts:

Dr. M. Sugata , General Manager, Ironmaking Technology Laboratory
Prof. Y. Kawai, Executive Advisor

References:

- Japan Metal Bulletin (JMB), February 9, 1988.
- Metal Bulletin, February 11, 1988.
- American Metal Market, March 4, 1988.
- "New Melting Process" (Nippon Steel Corporation), 1988, Steltech Interoffice letter, File No. 300 02, March 18.
- "Nippon Steel Postpones Closure of Two of its Blast Furances", 1989, American Metal Market, October 16, (Stelco Business Highlights, November 7, 1989).
- "NSC Blast Furnace Shatters Service Life Record", 1990, I&SM, August, p10, news item.

A 7. SUMITOMO SCRAP - MELTING METHOD

Developer:

Sumitomo Metal Industries

Purpose:

To use steel scrap, alone, as material for melting and refining into high grade steel economically.

Principles:

Process steps include:

- lay lump coke on bottom of converter,
- ignite coke and burn with bottom-blown oxygen,
- change one-half of the scrap charge,
- blow oxygen from the top until whole inner space is red hot,
- add second half of steel scrap charge along with lump coal and limestone,
- continue blowing until tap temperature and composition are achieved.

Status:

- Tested in 10-tonne pilot furnace; heating costs were 20 percent lower than in EAF.

Potential Contacts:

H. Ishida
K. Marukawa
S. Anezaki
T. Hirata
S. Shiode

References:

- Japan Metal Bulletin, January 11, 1986.
- H. Ishida et al, "Development of Scrap Melting Process by STB Test Converter", 1988, Proceedings Process Technology Conference, AIME/ISS, pp 233 to 239.

A 8. TULA PROCESS

Developer:

Tulachermet, USSR

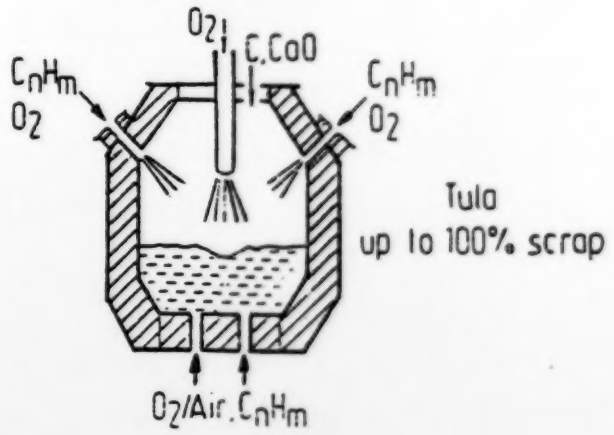
Purpose:

To produce steel in a converter using a 100 percent scrap charge.

Principles:

Figure 51 is a schematic of the Tula process.

Figure 51: Tula Process Schematic for Steelmaking with up to 100 percent Scrap Charge (ST, 1987)



The converter is equipped with multichannel bottom tuyeres for gaseous oxygen and fuel hydrocarbon (natural gas) injection. The bottom tuyere design and construction enables the reagent supply to be controlled over a wide range, which is necessary for the bottom tuyeres to serve as:

- heating devices for the initial stages, and
- blowing devices for the subsequent stages.

Besides the bottom tuyeres, the converter is also equipped with side burners through which oxygen and fuel are fed in the initial stage of heating. After changing the blowing conditions, the side burners can be used successfully for off-gas post-combustion. The choice of slope and layout for the side burners optimizes the post-combustion.

A moving oxygen top lance can also be used to permit an increase in the quantity of scrap to be treated.

Coals from different Soviet coal fields have been the main energy source, most commonly Donetsk anthracite, 0 to 6 mm in size (2% S and 16 to 22% ash).

The use of high purity oxygen for scrap heating and melting is not obligatory; purity can range down to 85 percent oxygen, permitting some cost reduction. Higher purity oxygen, which is top-blown conventionally, is used only in the final stage of heating, i.e. during the last 10 to 20 minutes.

The melting process starts with charging scrap, lime and coal into the converter. The scrap and additions are heated as a result of burning the coal and natural gas with oxygen; control methods for heating and final melting have been developed which prevent slag foaming and metal slopping and spitting, resulting in high steel yield.

Average results achieved in trials on a converter using 100 percent scrap:

• oxygen consumption	101.4 Nm^3/ts
• natural gas consumption	33.0 Nm^3/ts
• coal consumption	58.5 kg/ts
• lime consumption	70.0 kg/ts
• yield steel/scrap	91 to 94%
• lining life	similar to that of top-blown converter
• steel sulfur	0.012% Max
• carbon content at meltdown	0.2 to 2.0%

Status:

- Technology has been tested on a converter (size not stated)
- Technology is for sale - for the construction of new steelworks and/or modification of existing converters up to 250 t. Technology can be used intermittently or all the time.
- Economic analysis indicates that, using the 100 percent scrap charge, the prime cost of every tonne of steel output (in ingots and continuously cast billets) is 17 to 19 percent lower compared to conventional converter practice.

Potential Contacts:

Prof Kalganow

References:

- Prof Kalganow (USSR), "The Tula Process for Converter Steelmaking using a 100% Scrap Charge", 1987, Steel Times (ST), July.
- "The Tula Process: Experiences in the Industrial Application of a Steel Converter for 100% Scrap Melting", 1987, 15th Advanced Technology Symposium, "Advanced Melting Technologies", Myrtle Beach, October.

B 1. KLÖCKNER-ELECTRIC STEEL (K-ES) PROCESS

Developer:

Klöckner CRA Technology Group

Purpose:

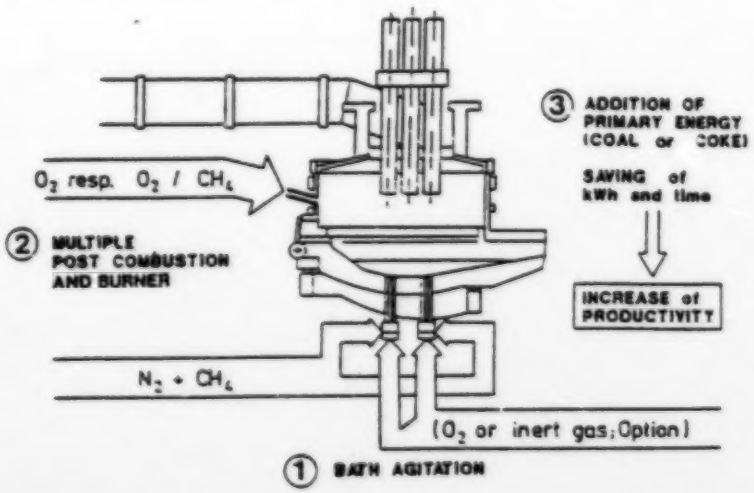
To decrease the electricity requirements of the EAF steelmaking process and to enable the recycling of EAF dust.

Principles:

- Coal and oxygen are injected into an electric arc furnace (presumably through the bottom).
- The use of the coal saves electrical energy and provides the reductant which may permit the recycling of the EAF dust.

Figure 52 shows the elements of the K-ES process.

Figure 52: Elements of K-ES Process (Manzocco et al, 1989)


3 ADDITION OF PRIMARY ENERGY (COAL or COKE)
SAVING of kWh and time
INCREASE of PRODUCTIVITY
O_2 resp. O_2 / CH_4
2 MULTIPLE POST COMBUSTION AND BURNER
N_2 + CH_4
(O_2 or inert gas; Option)
1 BATH AGITATION

Status:

- Developed, by Klöckner CRA Technology Group in Japan.
- Ferriere Nord SpA, Ossopo, Italy has placed the first order in Europe. Plant came on stream in 1989.
- Acciaierie Venete SpA, Italy, is also reported to be a licensee.

Potential Contacts:

Dr. R. M. Flesch
Dr. A. Hauck (since resigned)
Dr. W. Schlebusch

References:

- L. Manzocco et al, "Advances in Electric Steelmaking in the Ferriere Nord SpA Plant, Ossoppo, Using the K-ES Process", 1989, 3rd European Electric Steel Congress, Bournemouth, UK, October, preprint.
- Iron and Steel Engineer, February 1989, pp D-8 to D-19.
- "Variations on a Theme by Klöckner", 1988, Steel Times International, September, pp 39 and 41.
- K. Brotzman and E. Fritz, "A Step Towards More Economic Steelmaking", 1988, Steel Technology International, pp 136 to 141.
- L. L. Teoh, "Electric Arc Furnace Technology: Recent Developments and Future Trends", 1989, Ironmaking and Steelmaking, Vol 16, No. 5, pp 303 to 313.
- E. Fritz et al, "K-ES Uses Fossil Fuels to Boost Productivity and Reduce Electricity Consumption", 1988, Steel Times, Vol 214, No. 5, pp 250 to 253.
- J. R. Grossman and H. G. Geck, "Klöckner Steelmaking Techniques for the Production of Stainless Steel", 1989, World Steel and Metalworking Manual, Vol 10, pp 116 to 120.
- P. Greis et al, "Metec '89 - Technical Trends in Metallurgical Plant and Technology", 1989, Metallurgical Plant and Technology, Vol 4, p 18 to 30.
- "Klöckner Stahltecknik EAF-Injection", KCT advertising brochure.
- 16th Conference of OBM/Q-BOP Users and Engineering Licensees, 1989, October 23 to 26, two overhead slides.
- L. Manzocco et al, "EAF Steelmaking Benefits from K-ES Process", 1990, Metal Bulletin Monthly (MBM), March, pp 51 and 53.
- W. Ballandino et al, "The New Oval Bottom Tapping Furnace at Acciaierie Venete", 1989, Proceedings, International Congress on New Developments in Metallurgical Processing (METEC 89), VDEH Düsseldorf, FRG, May 22 to 24, Section V/5, pp 1 to 14.
- R. J. Fruehan, "A Nontechnical Introduction to Electric Furnace Steelmaking - Part VI", 1989, I&SM, August, pp 52 to 53.
- R. M. Flesch et al, "The KCT Process Family: Clean and Economic Steel Manufacturing", 1990, International Symposium/Workshop on Future Ironmaking Processes, Steltech, Hamilton, Ontario, Canada, June 14 and 15, pp 2-1 to 2-23.

C 1. ENERGY OPTIMIZING FURNACE (EOF)

Developer:

Korf Group
Korf's Brazilian Steel Mill, Compania Siderurgica Pains

Purpose:

To replace the open hearths at Compania Siderurgica Pains with the most cost-effective steelmaking process possible.

Principles:

The EOF process (Figure 53) is essentially an oxygen steelmaking process using combined side blowing. Oxygen is injected horizontally through specially designed tuyeres into the molten bath, and oxygen is blown into the furnace atmosphere by water-cooled injectors.

Oxygen injected underneath the liquid level oxidizes carbon, forming CO which results in bath agitation.

The resulting intense splashing multiplies the steel surface exposed to the oxygen injected above the bath, accelerating carbon oxidation. The CO formed in the bath is burned to CO_2 above the bath, with some of the heat being absorbed by the bath and the remainder being used to preheat the scrap of the charge (average temperature of scrap at drop may exceed 800°C, with local peaks to 1100°C).

The flexibility of the EOF permits the use of a wide percentage of scrap and, hence, essentially two modes of operation.

At PAINS, where hot metal comprises, normally, 60 percent of the charge, and the steel is tapped completely from the furnace at the end of each heat, the preheated scrap is dropped onto the hearth and the hot metal is poured onto it. The carbon in the hot metal is sufficient to provide the heat required for processing. Both submerged and top oxygen blowing start together immediately the hot metal has been poured.

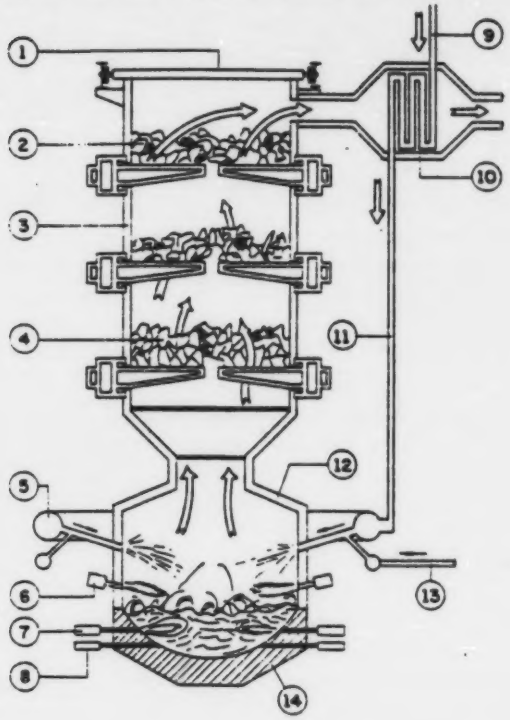
With higher proportions of scrap (up to 100 percent) a liquid steel heel is left in the furnace at each tapping. Coal fines are injected into the hot heel through special tuyeres until its carbon content increases to about three percent. Preheated scrap is then dropped in one or more batches and the oxygen blow is started (both submerged and top blowing).

In either mode of operation, the hot gases leave the furnace through the central hole in the roof and proceed through the scrap preheater.

(While this is essentially on oxygen steelmaking process, the reaction vessel has more the shape of an EAF - and the technology may be more readily adaptable to EAF plants.)

Carbon fines can be any high fixed carbon, low volatile matter material including coke breeze, petroleum coke, anthracite, or low volatile bituminous coal. Sulfur should be 1.1 percent (max), and ash levels 12 percent (max).

Figure 53: EOF (Energy Optimizing Furnace) Scheme (Weber and Pfeifer, 1986)


1 - SCRAP CHARGING
2 - COLD SCRAP
3 - SCRAP PREHEATER
4 - PREHEATED SCRAP
5 - HOT AIR MAIN
6 - OXY FUEL BURNERS
7 - O_2 SUBMERGED TUYERES
8 - COAL INJECTION
9 - COMBUSTION AIR (COLD)
10 - RECUPERATOR
11 - COMBUSTION AIR (PREHEATED)
12 - WATER COOLED ELEMENTS
13 - ADDITIONAL OXYGEN
14 - FURNACE BOTTOM

Status:

- Pilot plant at PAINS, without preheater, 22 tonnes/heat in 1981/82.
- Installation and commercial operation at PAINS of a 28 tonnes/heat unit with scrap preheater specifically designed to suit the metallic charge at PAINS in 1983/85.
- By July 1989:

  - two EOFs operating in Brazil, 30 tonnes/heat each, at PAINS, producing 440 000 tonnes/yr steel.
  - one EOF (end of 1988) at Companhia Siderurgica Aliperti in São Paulo, Brazil, 60 tonnes/heat producing 400 000 tonnes/yr steel (thermal efficiency even better than for 30 t furnaces).
  - one 80-tonne EOF under construction for Tata Iron and Steel Co, India. Startup scheduled for mid 1990.

  All the above operate, or will operate, on hot metal and scrap, ratio hm: scrap ranging from 55:45 to 70:30.

  - one 40-tonne EOF to be built for Ocean State Steel Inc. in East Providence, RI. It will be the first to operate on 100 percent scrap and will produce billets for the rolling mills of Connecticut Steel in Wallingford, Connecticut. Engineering is finalized; startup was

scheduled for second half of 1990 (will replace two existing old 40-ton EAFs), but now rescheduled to the end of 1991.

Contacts:

- B. Rollinger - President - Korf Lurgi Stahl Engineering GmbH
- John E. Bonestell - Exec VP, Korf Steeltec Inc, Charlotte, NC
- H. Eichberger - Manager Steel Plant Technology, KLSE

References:

- R. Weber and H. C. Pfeifer, "The EOF Process: Performance and Outlook", 1986, International Conference of Iron and Steel Technology in Developing Countries, São Paulo, Brazil, November.
- B. Rollinger, "Korf's EOF System is Working Out in Brazil", 1989, American Metal Market, Extra Edition, July 21, Vol 97, No. 141.
- W. Korf, "Steel Industry Focus Should be on Quality", 1986, American Metal Market, September 9.
- J. E. Bonestell et al, "EOF (Energy Optimizing Furnace) Steelmaking", 1985, Iron and Steel Engineer, October, pp 16 to 22.
- R. J. Fruehan, "Alternate Scrap Melting Technologies, Part II", 1987, I&SM, April, pp 9 to 12.
- "Future Steelmaking", Report of AISI Task Force on Direct Steelmaking, March 1988.
- R. J. Fruehan, "A Nontechnical Introduction to Electric Furnace Steelmaking, Part VI", 1989, I&SM, August, pp 52, 53.
- R. Weber and B. Rollinger, "Optimization and Improvement of the EOF Process at the C. S. Pains and C. S. Aliperti Steel Plants in Brazil", 1989, Seminar on the Economic and Technical Aspects of the Modernization of the Steel Industry, United Nations Economic Commission for Europe, Kraków, Poland, May 15 to 19.
- B. Rollinger, "Energy Optimizing Furnace - A Highly Flexible Process", 1989, Steel Technology International (STI), pp 165 to 168.
- R. Weber and B. Rollinger, "The EOF - Industrial Application at Two Brazilian Steel Shops", 1989, Proceedings, International Congress on New Developments in Metallurgical Processing (METEC 89), VDEh, Düsseldorf, FRG, May 22 to 24, Section V/3, pp 1 to 18.
- J. Bonestell, "Energy Optimizing Furnace: Leapfrog Technology for the Steel Industry", 1989, AISE Utah Invitational Meeting, Park City, Utah, June 9.
- B. Rollinger, "The EOF - Cost Efficiency of a New Metallurgical Process", 1989, American Metal Market/World Steel Dynamics' Steel Survival Strategies IV, New York, NY, June 27.
- B. Rollinger, "High Efficiency Use of Chemical and Physical Heat", (in EOF), 1987, Translation from "Handelsblatt", No. 219, Nov 13 to 14.
- "Ocean State Steel Works up to Total Scrap Charge", 1989, Steel Times International, March.
- "EOF - Steelmaking the New Way", KLSE advertising brochure.
- R. Weber et al, "Direct Use of Coal in EOF Steelmaking", 1990, International Symposium/Workshop on Future Ironmaking Processes, Steltech, Hamilton, Ontario, Canada, June 14 amd 15, pp 9-1 to 9-22.

C 2. DAIDO'S REACTOR PROCESS

Developer:

Daido Steel Co Ltd

A. Scrap-Melting

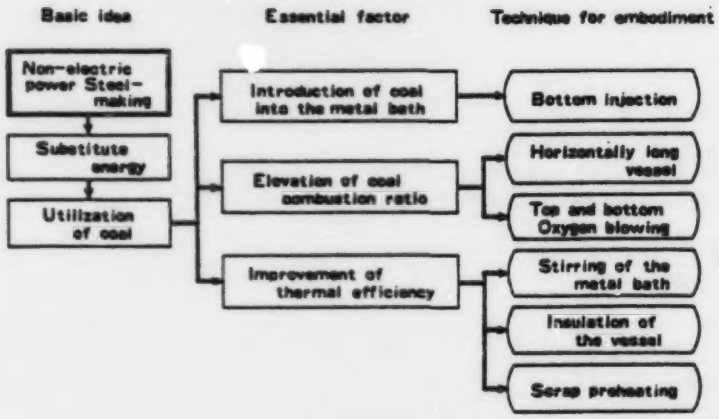
Purpose:

To melt scrap with carbon as the energy source in place of electric power.

Principles:

Figure 54 diagrams the development of Daido's reactor process.

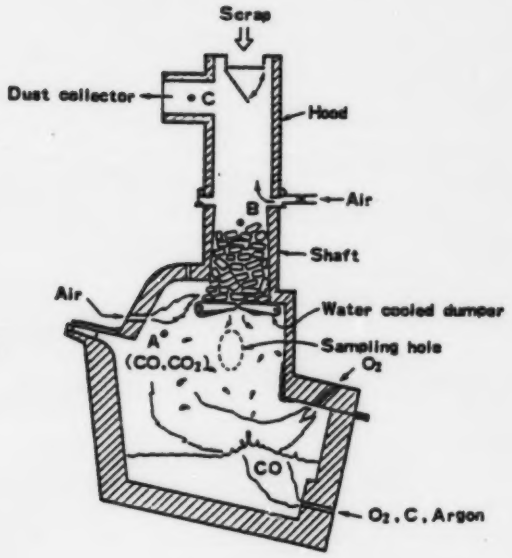
Figure 54: Conception of Development of Reactor Process (Sugiura et al, 1988)



The pilot reactor's capacity was one tonne of molten steel. In ordinary operation, 0.5 tonne of steel is discharged at every tapping, leaving a hot heel of 0.3 to 0.5 tonne. Scrap preheated by the gases from the reaction chamber is charged onto the hot heel. Oxygen and coal are bottom-blown into the melt and post-combustion oxygen is blown into the reaction chamber through the roof.

In the lower part of the furnace the bath is made shallow so as to increase the interface area of molten iron and high temperature gases. The furnace is tilted about 10° to make the depth of the molten iron/steel greater at the submerged tuyere side so that the bottom-blown gas does not blow through. CO gas is generated continuously by the blowing of carbon powder and oxygen into the bath from the bottom. The top-blown oxygen converts the CO to CO_2 (post-combustion) to heat the melt further.

Figure 55: Schematic Illustration of Reactor (Sugiura et al, 1988)



References:

- S. Sugiura et al, "Development of a New Non-Electric Scrap Melting Process", 1988, Transactions ISIJ, Vol 28, pp 325 to 332.
- S. Sugiura et al, "Melting Direct Reduced Iron by Combustion of Carbon", 1988, Steel Technology International, pp 114 to 117.
- N. Demukai, "Development of Reactor Steelmaking", 1989, Camp-ISIJ, Vol 2, English Abstract, (full paper in Japanese).

B. DRI-Melting

Purpose:

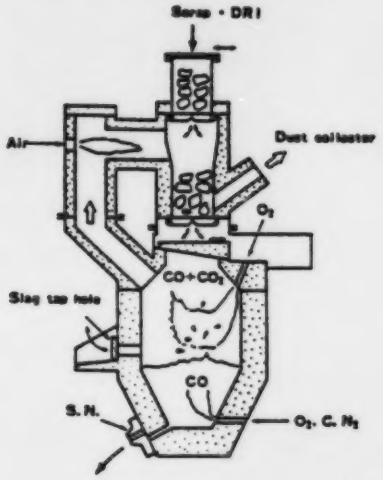
To test the melting of DRI in the reactor, to broaden the sources of ferrous materials.

Principles:

Principles were essentially the same as for scrap melting operation except that the preheating temperature had to be held to 600°C maximum so as to minimize oxidation of the DRI.

Figure 56 is a schematic of the Daido reactor charging DRI.

Figure 56: Schematic Illustration of Reactor with Direct Reduced Iron (Sugiura et al, 1988)



Status:

- Tests in a 0.5 tonne/hr reactor for both scrap and DRI.
- "The practical application of the reactor is very hopeful."
- DRI can be used satisfactorily as the material for steelmaking in the non-electric scrap melting system currently being developed by Daido.

Potential Contacts:

- Saburo Sugiura - Central Research Laboratory
- Senji Fujita Daido Steel Co Ltd
- Noboru Demukai Daido-cho, Minami-ku, Nagoya 457

References:

- S. Sugiura et al, "Melting of Direct Reduced Iron in a Non-Electric Power Scrap Melting Furnace", 1988, Transactions ISIJ, Vol 28, pp 1014 to 1020.

V. DIRECT REDUCTION

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5. Iron Carbide Process 129

1. MIDREX PROCESS

Developer:

Midrex Corporation

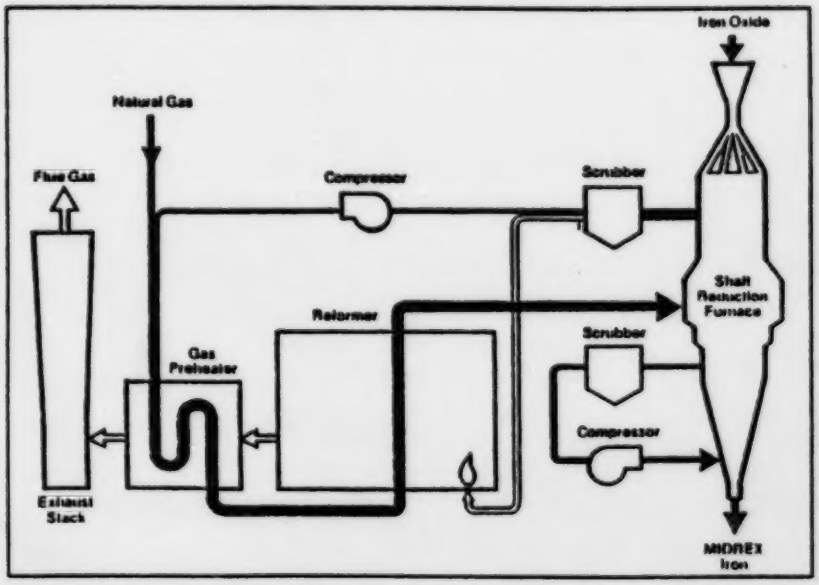
Purpose:

To develop a viable gas-based direct reduction process.

Principles:

The flowsheet of the Midrex process is shown in Figure 57.

Figure 57: Midrex Process Flowsheet (Hoffman, 1984)



The Midrex process comprises essentially a gas-reforming unit and a shaft-reduction furnace.

The reduction furnace is divided into two zones: the reduction zone and the cooling zone. In the reduction (upper) zone, the descending iron oxide is progressively heated, metallized and carbonized by the ascending hot reducing gases. The reducing gases, prepared in the gas reformer, enter the shaft furnace at a temperature of 800°C to 870°C through numerous openings around the periphery of the shaft furnace at about its midpoint. The reducing gases, approximately 55 percent H_2 and 35 percent CO, heat and reduce the iron oxide to direct reduced iron (DRI).

The spent reducing gas, or top gas, is cooled and cleaned in a scrubber. About two-thirds of the cleaned top gas is returned to the gas reformer to produce, with the controlled addition of natural gas, fresh reducing gases. The oxygen carriers CO_2 and H_2O in the returning top gas supply sufficient

oxidant for the catalytic reforming of the natural gas. The remaining one-third of the top gas is burned to heat the reformer tubes.

In the lower section of the furnace, the cooling zone, the descending hot, metallized (92 to 93 percent) material is cooled to below 50°C by a closed-loop, recirculating, gas system. By the controlled addition of natural gas to this cooling gas, the carbon content of the metallized material can be increased to two percent. The cooling gas leaving the furnace is cooled, washed in a scrubber, and recycled through the cooling zone.

The hot flue gases of the reformer are used to preheat the combustion air and the top gas/natural gas mixture flowing to the reformer tubes. This heat recuperation results in the outstandingly low energy consumption of the Midrex process. The flue gases exiting to the atmosphere are free from dust. The water from the scrubbers is cleaned in a clarifier and recycled to the process.

If the metallized product is not consumed in an adjacent electric arc furnace, a modified Midrex process concept to produce hot briquetted iron (HBI) can be offered. In such a case, the hot metallized material is fed directly into briquetting machines beneath the reduction furnace. The resulting dense briquettes are much more resistant to reoxidation than "normal" DRI. The HBI can be quenched in water, stored outside, and transported under wet climatic conditions - all of which would be catastrophic with DRI pellets.

Status:

- Commercial; the direct reduction process in widest use.

Contact:

Mr. Donald J. Werner, Vice President - Sales and Licensing
Midrex Corporation, Charlotte Plaza, Charlotte, NC 28244, USA

References:

- T. H. Hoffman, "The Midrex DR Process - Environmentally Sound Route to Iron Making", 1984, Direct from Midrex, 3rd Quarter, pp 8 to 10.
- F. Rose and H. Walden, "Midrex and SL/RN Choices for Direct Reduction", 1989, Steel Technology International, pp 91 to 95.

2. HyL III PROCESS

Developer:

HyLSA S.A. de C.V.

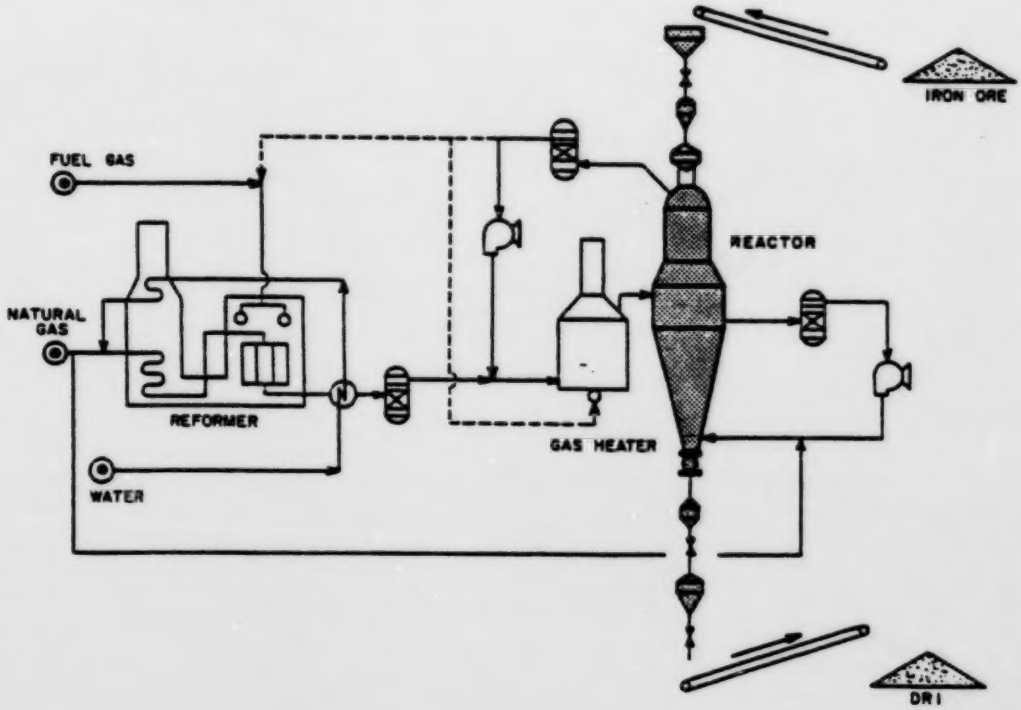
Purpose:

To develop a continuous, viable, gas-based, direct reduction process (as compared to HyL I which employed stationary retorts).

Principles:

The basic flowsheet (Figure 58) looks similar to that of the Midrex process.

Figure 58: HyL III Process Diagram (Quintero and Becerra, 1987)



The process is made up of two independent loops, the cooling loop, and the reduction loop.

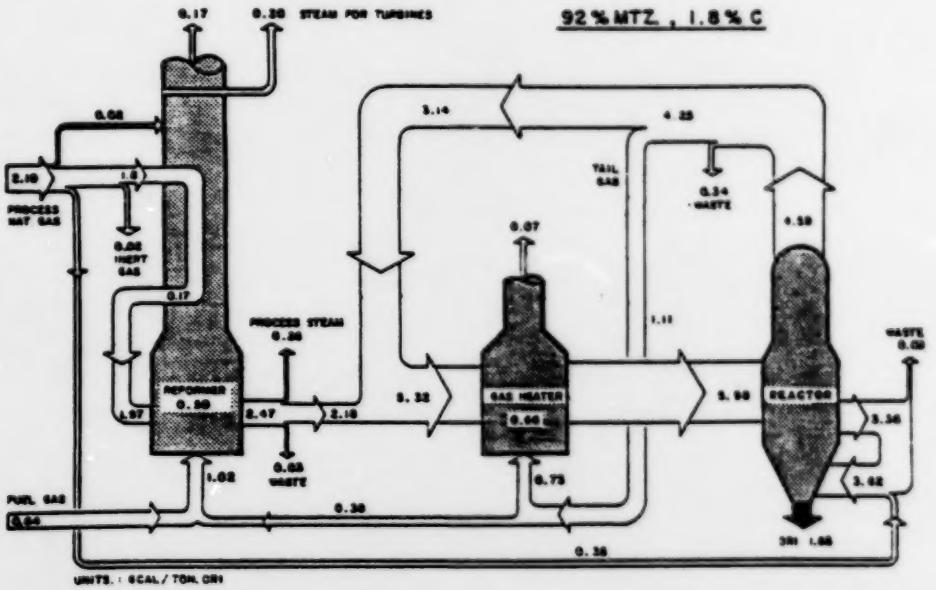
In the reduction loop, the reformed gas coming from a natural gas-steam reformer is mixed with the recycled gas, and is heated up to the required temperature to carry out the iron ore reduction.

In the cooling loop, the recycled gas is mixed with natural gas and fed to the lower part of the reactor. The cool gas flows countercurrently to the solid to cool it, but also some reduction and carburization take place. Since the HyL III reactor operates at high pressure (6 kg/cm^2), there are sealing mechanisms that help to keep a constant gas pressure while feeding iron ore and discharging DRI.

Since the recycled gas in the reduction loop is not passed through the natural gas reformer, the HyL III process has practically no limitations regarding the sulfur content of the iron ore to be reduced.

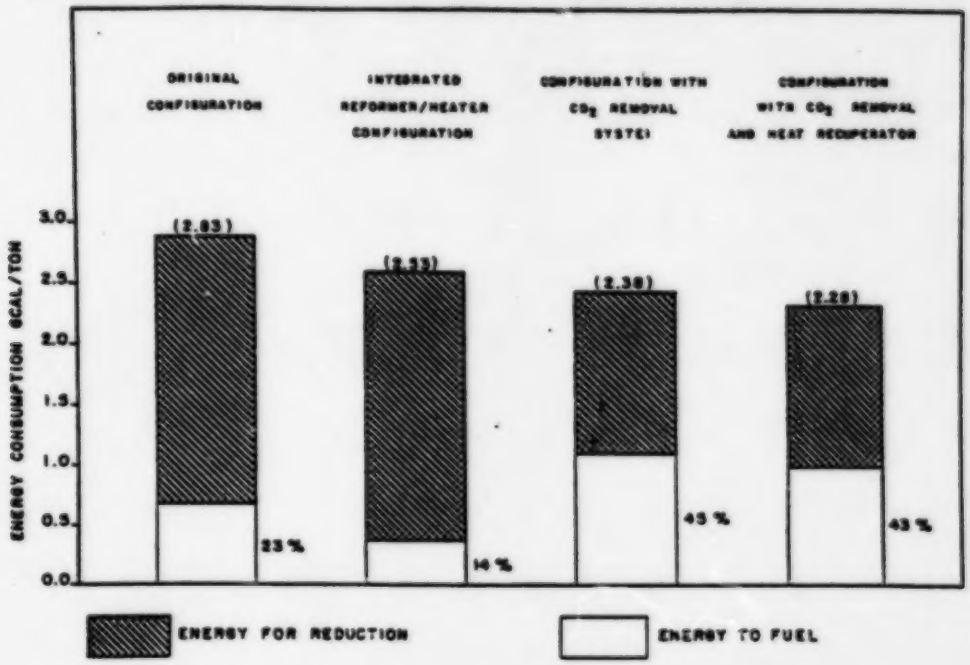
Figure 59 shows the energy balance of the original HyL III process flowsheet. As can be seen, the combustion gases of the reformer contain excess heat which can be used to raise steam to move turbines so that the electric energy consumption becomes zero. In this way, the plant is very reliable regarding the continuous operation of compressors and pumps.

Figure 59: Process Energy Diagram (Quintero and Becerra, 1987)



HyL has developed several variations of the HyL III process; their respective energy requirements are noted in Figure 60.

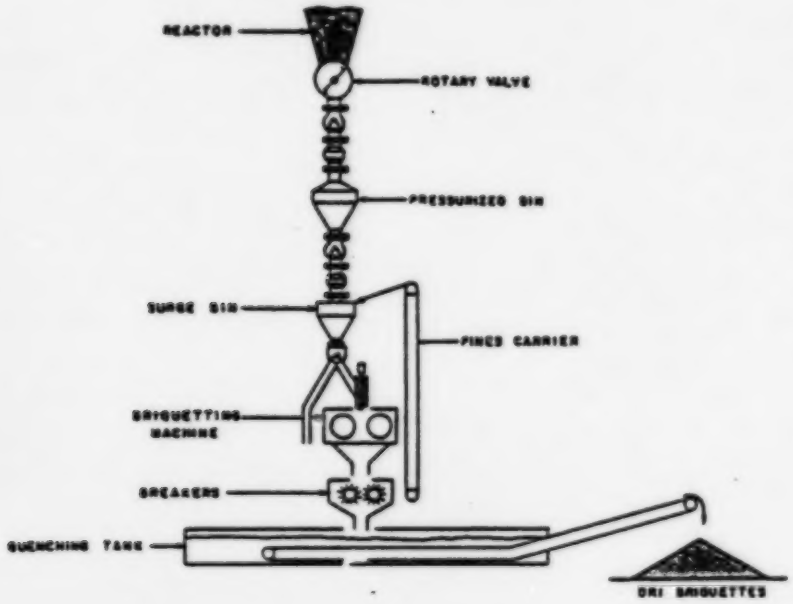
Figure 60: Energy Requirements - HyL Variation (Quintero and Becerra, 1987)



If the direct reduction plant is integrated with a steelmaking plant, it would likely be advantageous to feed the hot DRI directly to the electric arc furnace. When hot DRI at 600°C is fed to an EAF, as much as 140 kWh of electricity can be saved per tonne of liquid steel.

For a merchant plant, the hot DRI can be sent to a briquetting machine in line with the reactor as shown in Figure 61. The briquettes produced have a very high density because of the high temperature of the DRI, which can be as high as 800°C. In general, when DRI temperature is higher than 650°C, it is possible to produce briquettes with very low porosity so that their stability is very high.

Figure 61: In-Line Hot Briquetting (Quintero and Becerra, 1987)



The system for hot briquetting directly from the Midrex process would be similar.

Status:

- Commercial since 1980; chief gaseous reduction process rival to Midrex.

Contacts:

Mr. R. Quintero - The Iron and Steelmaking Technology Division
Mr. J. Becerra HyLSA S.A. de C.V.

References:

- R. Quintero and J. Becerra, "HyL III: A Continuing Evolution Process", 1987, Ironmaking Conference Proceedings, AIME/ISS, Vol 46, Pittsburgh, PA, March 29 to April 1, pp 421 to 434.

3. SL/RN PROCESS

Developer:

Stelco Inc.
Lurgi Chemie
Republic Steel Co.
National Lead Co.

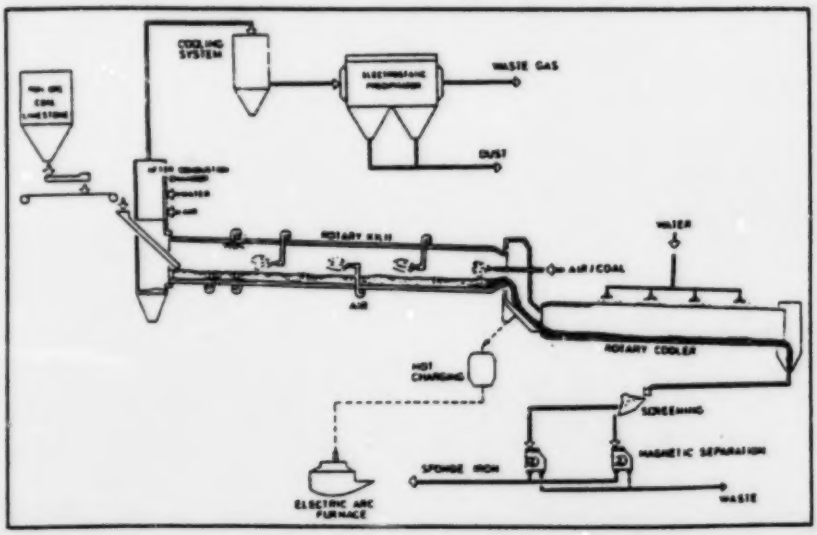
Purpose:

To develop a viable coal-based direct reduction process.

Principles:

Figure 62 is a flowsheet of the SL/RN process.

Figure 62: Flowsheet of SL/RN Process (Rose and Walden, 1989)



The SL/RN process uses a rotary kiln reactor of special design. The raw materials, coal, ore, and limestone (or dolomite) are proportionally charged into the kiln, where they are heated and the iron ore is reduced to DRI. The limestone or dolomite acts as a sulfur scavenger. The DRI is cooled in an indirect cooler, the nonmagnetic fraction being separated in a downstream separating stage.

The magnetic fraction, the DRI product, is used directly for steelmaking in electric arc furnaces. DRI fines can be briquetted prior to charging into the electric arc furnace or directly blown into the melt.

If low-ash coal is used, char recycling is applied to reduce coal consumption.

Hot charging of the entire kiln charge is also practiced in two SL/RN plants. In both plants low-ash coals are used and pig iron is produced as an intermediate product in electric reduction furnaces. This concept imparts capital investment savings and reduced electric energy consumption due to the hot charge.

The hot waste gases leave the kiln at the feed end. After passing through a dust chamber, they enter the after-combustion chamber, where gaseous and solid combustibles are burned out. The waste gases are then cooled and are dedusted in electrostatic precipitators, scrubbers or bag filters.

Instead of cooling the gases in a spray tower, as in most DR plants, waste heat boilers can be installed to recover their sensible heat. The steam generated is usable for heating or can be converted to electric energy and used for steel melting in electric furnaces.

Consumption figures for the Midrex and SL/RN processes are provided in Table III (Lurgi markets both).

Table III: Consumption Figures, Midrex and SL/RN (Rose and Walden, 1989)

DR Plant (400 000 - 600 000 tpy DRI)	Midrex	SL / RN
Pellets / lump ore (min. 66 % Fe)	1,41 - 1,45 t	1,43 - 1,45 t
Natural gas	2,3 - 2,5 Gcal	
Coal		380 - 440 kg fixed carbon
Electrical Energy	100 kWh	70 - 80 kWh
Water	1 - 1,5 m^3	2,5 m^3 (1,5 m^3 with waste heat recovery)
Manpower	0,35 - 0,45 manhours	0,35 - 0,6 manhours
Maintenance, repairs and other operating supplies	5 - 6,5 US $	5 - 6,5 US $

Status:

- Commercial; chief process among coal-based direct reduction processes.

Contact:

Lurgi Canada Ltd
100 Adelaide Street West
Toronto, Ontario

References:

- F. Rose and H. Walden, "Midrex and SL/RN Choices for Direct Reduction", 1989, Steel Technology International, pp 91 to 95.

4. PLASMARED PROCESS

Developer:

SKF Steel, Sweden

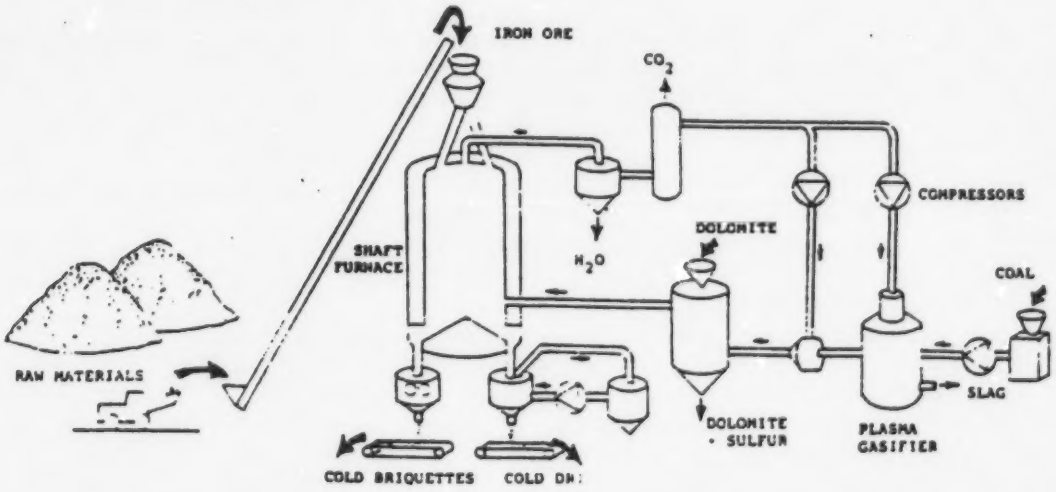
Purpose:

Program purpose was to develop new metallurgical processes that could be used economically on a smaller scale than "today's" methods. The objectives included lower energy requirements, better energy efficiency, wider energy flexibility, and reduced environmental impact.

Principles:

Figure 63 is a diagram of the Plasmared process.

Figure 63: Plasmared Process (Herlitz et al, 1984)



Coal, or another fuel, reacts with an oxidizing agent, e.g. water and/or oxygen, to form a reducing gas consisting mainly of hydrogen and carbon monoxide. The heat energy needed for the gasification reactions is supplied wholly or partly through plasma generators. The ash in the coal melts and is tapped from the gasifier as a liquid slag. Before entering the shaft (reduction) furnace, the hot gas is desulfurized in a dolomite filter similar to the type used in the Wiberg process.

Status:

- In 1980 an old Wiberg direct reduction facility for the production of 25 000 t/yr DRI was converted to a Plasmared plant. The new unit was started up in January 1981.

- After a few months of initial problems, the plant has operated continuously as a production unit with a capacity of approximately 50 000 t/yr DRI, using LPG as fuel.
- In May 1982, the gasifier was modified so that a coal/water slurry could be used as fuel. Since then, the plant was in continuous production using mainly coal as fuel.
- All DRI produced in this plant was consumed in SKF Steel's melt shop.
- The plant was also used for production-scale tests of various coal and ore grades.
- Plasmared at the SKF steel plant at Hofors has been shut down since early 1985 because the operation was too small to be economical. Larger projects have been considered for other locations in Sweden; however, none of the proposals has been sufficiently attractive to overcome local environmental objections and other negative factors.

Potential Contacts:

Sven O. Santen - SKF Plasma Technologies AB

References:

- H. G. Herlitz et al, " A New Family of Reduction Processes Based on Plasma Technology", 1984, Iron and Steel Engineer, March, pp 39 to 44.
- R. B. Smith and M. J. Corbett, "Coal-Based Ironmaking - A Study", 1985, ECSC-Sponsored Research Project, Agreement No. EC1-1274-B7240-84UK, BSC Ref: FR 158-3/852, September.
- S. C. Camacho et al, "Plasma Technology in Metallurgical Processing, Part II, Assessment of Development Problems and Future Prospects", 1987, I&SM, October, pp 34 to 35.

5. IRON CARBIDE PROCESS

Developer:

Hazen Research, USA (patents now held by Iron Carbide Holdings)

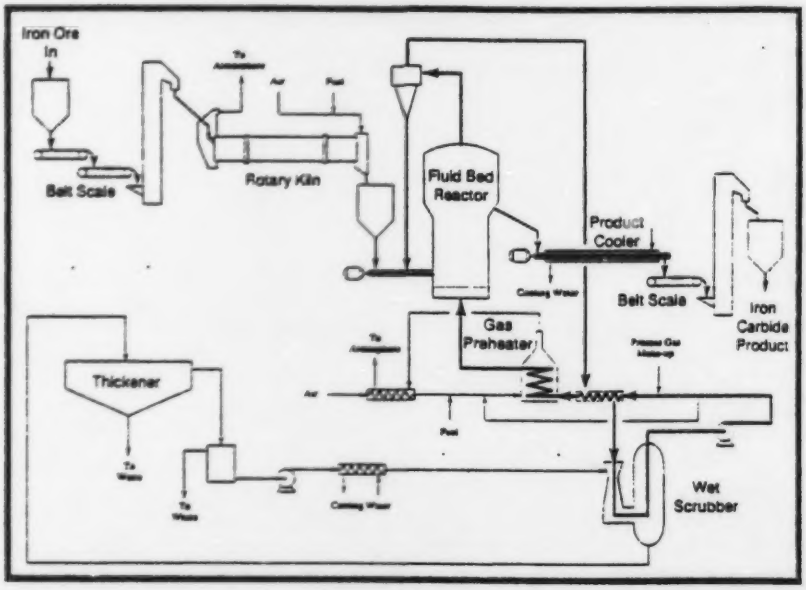
Purpose:

To reduce ore fines without the need for briquetting (stability in storage).

Principles:

The process is based on a fluidized bed reactor using natural gas to reduce ore fines to iron carbide. The flowsheet is shown in Figure 64.

Figure 64: Flowsheet - Iron Carbide Process (Evans, Stephens, and Williams, 1988)



Screened and classified iron ore is preheated and introduced into the fluid bed reactor, where a hot stream of a mixture of gases is forced up through the bed of ore, interacting to strip the oxygen from combination with iron (forming water), while carbonaceous gases provide a carbon atom for each three iron atoms, thus forming iron carbide - Fe_3C.

The water-laden off-gas (top of the reactor) is relieved of much of its dust burden in the cyclone atop the reactor, thence to the heat exchanger for cooling, and into the scrubber where the water vapor is condensed out of the stream along with remaining small dust particles.

The scrubbed gas, depleted of carbon and hydrogen, is reconstituted with make-up gas and is repressurized, passed through the heat exchangers to gain the temperature boost, and finally preheated to the 700°C reaction temperature for reentry at the bottom of the fluid bed reactor to repeat the cycle.

The requirements for a 1000t/day plant are:

natural gas	4×10^6 Gigajoules annually
iron ore	450 000 tonnes annually
electric power	73×10^6 kWh annually
employment	operation 35
	maintenance 15 to 20
water	nominal (process produces ~200 000 tonnes annually)
area	100 m x 200 m plus storage

Status:

- A 25 tonnes/day plant has been operating at Wundownie, near Perth, Australia, since March 1989.
- A 350 000 tonnes/year plant ($40 million US) is expected to come on stream, there, in early 1990.
- A feasibility study for a 1000 tonnes/day installation (location not specified) is being made in Australia.
- Other agreements provide for two plants with a capacity of 350 000 t/yr each to be built in North or South America.

Potential Contacts:

Mr. D. D. Evans - Iron Carbide Holdings Ltd
Mr. F. M. Stephens, Jr
Mr. W. E. J. Williams

References:

- D. D. Evans, F. M. Stephens Jr, and W. E. J. Williams, "Iron Carbide and the Production of Steel", 1988, information paper, Iron Carbide Holdings Ltd.
- Iron and Steel Engineer, February 1989, pp D-18, D-19.
- F. M. Stephens Jr, "Iron Carbide Offers an Alternative Source of Quality Iron", 1989, Steel Times International, July, pp 18 and 20.
- "Iron Carbide Plant Close to Start-Up", 1989, Metal Bulletin Monthly, March, news item, p 15.